UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

GLACIAL FORMATIONS AND DRAINAGE FEATURES

OF THE

ERIE AND OHIO BASINS

BY

FRANK LEVERETT

WASHINGTON
GOVERNMENT PRINTING OFFICE
1902

LETTER OF TRANSMITTAL.

University of Chicago, *March 13, 1901.*

Sir: I have the honor to transmit herewith the manuscript of a monograph by Mr. Frank Leverett on the Pleistocene geology of the region between the Ohio Valley and the Great Lakes. This is the second contribution of Mr. Leverett to the series of monographs in course of preparation on the glacial formations of the Northern States, and is a fit companion to his Monograph XXXVIII, on The Illinois Glacial Lobe. The plan of the monograph and the method of its development are essentially the same as those of its forerunner. As in the preparation of that volume, our working relations have been of the most intimate kind, and I join with the author in the hope that it may prove an acceptable contribution to the Pleistocene problems of the United States.

Respectfully, yours,

T. C. Chamberlin.

Hon. Charles D. Walcott,
Director of United States Geological Survey.

PUBLICATIONS OF UNITED STATES GEOLOGICAL SURVEY.

[Monograph XLI.]

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—Flora of the Laramie and allied formations, by Frank Hall Knowlton.

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CONTENTS.

ILLUSTRATIONS.

ABSTRACT OF VOLUME.

CHAPTER I. INTRODUCTION.—The area treated in this monograph extends from the Genesee Valley in New York westward across northwestern Pennsylvania and Ohio to central and southern Indiana, and southward from Lakes Ontario and Erie to the vicinity of the Allegheny and Ohio rivers. It includes the old drift of northwestern Pennsylvania, the Illinoian drift of Ohio, Kentucky, and southeastern Indiana, and the Wisconsin drift of the Maumee-Miami, Scioto, and Grand River lobes, as well as the drift of western New York. It includes the portions of the glacial Lakes Maumee, Whittlesey, and Warren, which border the Lake Erie Basin on the south and west, and also their westward outlets.

This chapter presents an outline of previous publications on the glacial geology of the region, and also outlines the geologic formations and the several sheets of drift there present.

CHAPTER II. PHYSICAL FEATURES.—The variations in altitude are great, ranging from about 250 feet up to nearly 2,500 feet above sea level in the drift-covered region south of Lake Ontario, and from below sea level if that basin be included. There are series of plains south of Lake Ontario separated by escarpments, and south of these is a greatly eroded table-land. Farther west are the Grand River and Scioto basins, bordered by eroded table-land, and still farther west is the low plain of the central Mississippi Basin, whose eastern border is found in western Ohio.

CHAPTER III. DRAINAGE SYSTEMS.—This discussion includes not only a description of the present systems of drainage, but also directs attention to important changes of drainage that have occurred and attempts to determine to some extent the causes of these changes.

CHAPTER IV. THE DRIFT BORDER, OR GLACIAL BOUNDARY.—It is found that the glacial boundary is not a unit, but is formed in part by the border of the Wisconsin drift, in part by the Illinoian drift, and in part by a sheet of drift that appears to be still older than the Illinoian.

CHAPTER V. THE OLDEST DRIFT (KANSAN OR PRE-KANSAN?).—This drift, which is exposed outside the Wisconsin drift in northwestern Pennsylvania, is shown to

have suffered a much greater amount of erosion and weathering than the Illinoian drift. Its characteristics are set forth, and the glacial drainage connected with it is discussed.

Chapter VI. The Illinoian drift.—This embraces the portion of the Illinoian drift exposed outside the Wisconsin drift from the reentrant angle in the glacial boundary in southern Indiana eastward to central Ohio, where its border passes beneath the Wisconsin drift border. Its structure and topographic expression and the character of the glacial drainage are discussed.

Chapter VII. The Sangamon soil and weathered zone.—The weathered zone and accompanying soils and peat beds which occur between the Illinoian drift and the overlying loess are described in their exposures outside the Wisconsin drift, and to some extent within the limits of that drift.

Chapter VIII. The loess and associated silts.—The Iowan drift does not appear to be exposed in this region outside the Wisconsin drift, but a deposit of silt of loess-like characteristics occupies the horizon of this drift sheet. It may be to some extent a dependency of the Iowan drift, for the loess in the vicinity of the Mississippi River is found to have that relation, as indicated in Monograph XXXVIII. The mode of deposition is, however, considered problematical.

Chapter IX. The Peorian or post-loessial soil and weathered zone.—The evidence of this interval between the loess deposition and the Wisconsin glaciation is found in the relative amounts of weathering displayed by the loess and the Wisconsin drift. It may also be inferred from the change in the attitude of the land by which better drainage conditions became prevalent in the Wisconsin than obtained in the Iowan stage of glaciation. The marked difference in the outline of the Iowan and Wisconsin borders also indicates an interval of some consequence.

Chapter X. The early Wisconsin drift.—The early Wisconsin drift is less extensively exposed in this region than in that covered by the Illinois glacial lobe, discussed in Monograph XXXVIII, there being in southwestern Ohio but one moraine and a narrow till plain which seem referable to this drift, while in central and eastern Ohio and northwestern Pennsylvania it has a still more limited exposure. In southeastern Indiana two moraines of the White River lobe and one of the Miami lobe seem referable to this drift. The present report embraces only the part of this drift extending from the Miami lobe eastward. It treats of both the drift and the outwash connected with it.

Chapter XI. The interval between the early and late Wisconsin drift.—The evidence of this interval is more clearly shown in the region covered by the Illinois glacial lobe than in this region, for there the border of the outer moraine of the late Wisconsin group is strikingly discordant with that of the neighboring moraine or moraines of the early Wisconsin group, while in this region there is not a marked discordance. There is, however, in this region, as well as in the Illinois region, a marked contrast in the topography of the moraines, those of the early Wisconsin having smooth ridges without lakes or deep basins on them, while

the late Wisconsin moraines present a hummocky surface, deeply indented by basins, and in places carry lakes. The interval, if measured by contrasts in weathering, seems much shorter than the Peorian and Sangamon interglacial stages.

Chapter XII. The main morainic system of the late Wisconsin stage.—This morainic system was brought to notice by Chamberlin in the Third Annual Report of this Survey as the "Terminal moraine of the second Glacial epoch." It is by far the strongest morainic system of the entire series. The morainic loops in the several lobes—Miami, Scioto, and Grand River—are taken up in the order named. The question of the equivalent system to the east of the reentrant angle of southwestern New York is left open. Till plains, eskers, and other features to the north of this morainic system are discussed, and also the outwash to the south so far as it is connected with the morainic system.

Chapter XIII. Minor moraines of the late Wisconsin stage.—The several moraines lying between the main morainic system and the shores of Lake Erie and Lake Ontario are taken up in natural groups, and with them the eskers and other features of the drift. Those of the Maumee-Miami Basin form one group, and those of the Scioto Basin another, while later moraines lying within the Maumee Basin are next considered, and then those which closely border Lake Erie. The chapter closes with the moraines and associated drumlins and eskers south of Lake Ontario. Attention is incidentally called to glacial lakes in connection with the discussion of the border drainage.

Chapter XIV. The glacial Lake Maumee.—This was the highest of the great glacial lakes which formed in front of the retreating ice sheet as it withdrew into the Huron and Erie basins. The chapter describes two beaches, and also other features of this glacial lake, together with the successive outlets past Fort Wayne, Indiana, and Imlay, Michigan.

Chapter XV. The glacial Lake Whittlesey.—This lake was a close successor to Lake Maumee, and stood only about 30 feet lower. The Belmore beach, which marks its shore, is described throughout its course from southeastern Michigan southward and eastward to its apparent terminus at Marilla, in western New York. The Ubly outlet, through which the lake discharged westward to the Saginaw Basin, and the Grand River outlet, which led from the Saginaw Basin to Lake Chicago, are briefly considered. As in the preceding chapter, the relation of the ice sheet to the extent of the lake forms an important subject. A marked warping of the eastern portion of the beach is also discussed and is shown to contrast strongly with the nearly perfect horizontality in Ohio and southeastern Michigan.

Chapter XVI. The glacial Lake Warren.—Lake Warren as here defined was a successor of Lake Whittlesey in the Huron and Erie basins. Its borders are marked by a complex system of beaches standing 40 to 75 feet below the level of the Belmore beach, two of which are known as the Arkona and Forest beaches. Lake Warren also extended into the Saginaw Basin and discharged across Michigan through

the Grand River outlet to Lake Chicago in the Lake Michigan Basin. The discussion is restricted to the part of the beaches which border the west and south sides of the Erie Basin. Attention is called to the marked warping displayed by the beaches in the eastern part of the Erie Basin, and the contrast with the nearly horizontal attitude to the west.

In this chapter the lowering of the lake from Lake Warren to Lake Iroquois is briefly considered, and the probable relations of the lake to the ice sheet are set forth.

Chapter XVII. Soils.—The soils are classified according to their origin, the following classes being recognized: Residuary soils, bowlder-clay soils, gravelly soils, sandy soils, loamy soils grading into fine silts, peaty or organic soils.

MICHIGAN

1 MASON
2 LAKE
3 OSCEOLA
4 CLARE
5 GLADWIN
6 ARENAC
7 HURON
8 BAY
9 MI[redacted]LAND
10 ISABELLA
11 MECOSTA
12 NEWAYGO
13 OCEANA
14 MUSKEGON
15 MONTCALM
16 GRATIOT
17 SAGINAW
18 TUSCOLA
19 SANILAC
20 ST.CLAIR
21 LAPEER
22 GENESEE
23 SHIAWASSEE
24 CLINTON
25 IONIA
26 KENT
27 OTTAWA
28 ALLEGAN
29 BARRY
30 EATON
31 INGHAM
32 LIVINGSTON
33 OAKLAND
34 MACOMB
35 WAYNE
36 WASHTENAW
37 JACKSON
38 CALHOUN
39 KALAMAZOO
40 VAN BUREN
41 BERRIEN
42 CASS
43 ST.JOSEPH
44 BRANCH
45 HILLSDALE
46 LENAWEE
47 MONROE

INDIANA

1 LAPORTE
2 ST.JOSEPH
3 ELKHART
4 LAGRANGE
5 STEUBEN
6 DEKALB
7 NOBLE
8 KOSCIUSKO
9 MARSHALL
10 STARKE
11 PULASKI
12 FULTON
13 WHITLEY
14 ALLEN
15 ADAMS
16 WELLS
17 HUNTINGTON
18 WABASH
19 MIAMI
20 CASS
21 CARROLL
22 HOWARD
23 GRANT
24 BLACKFORD
25 JAY
26 RANDOLPH
27 DELAWARE
28 MADISON
29 TIPTON
30 CLINTON
31 BOONE
32 HAMILTON
33 HENRY
34 WAYNE
35 HANCOCK
36 MARION
37 HENDRICKS
38 MORGAN
39 JOHNSON
40 SHELBY
41 RUSH
42 FAYETTE
43 UNION
44 FRANKLIN
45 DECATUR
46 BARTHOLOMEW
47 BROWN
48 JACKSON
49 JENNINGS
50 RIPLEY
51 DEARBORN
52 SWITZERLAND
53 JEFFERSON
54 SCOTT
55 WASHINGTON
56 CLARK
57 FLOYD
58 HARRISON

OHIO

1 WILLIAMS
2 FULTON
3 LUCAS
4 OTTAWA
5 LAKE
6 ASHTABULA
7 TRUMBULL
8 GEAUGA
9 CUYAHOGA
10 LORAIN
11 ERIE
12 SANDUSKY
13 WOOD
14 HENRY
15 DEFIANCE
16 PAULDING
17 PUTNAM
18 HANCOCK
19 SENECA
20 HURON
21 MEDINA
22 SUMMIT
23 PORTAGE
24 MAHONING
25 COLUMBIANA
26 STARK
27 WAYNE
28 ASHLAND
29 RICHLAND
30 CRAWFORD
31 WYANDOT
32 ALLEN
33 VAN WERT
34 MERCER
35 AUGLAIZE
36 HARDIN
37 MARION
38 MORROW
39 KNOX
40 HOLMES
41 COSHOCTON
42 TUSCARAWAS
43 CARROLL
44 HARRISON
45 JEFFERSON
46 BELMONT
47 GUERNSEY
48 MUSKINGUM
49 LICKING
50 DELAWARE
51 UNION
52 LOGAN
53 SHELBY
54 DARKE
55 MIAMI
56 CHAMPAIGN
57 CLARK
58 MADISON
59 FRANKLIN
60 PICKAWAY
61 FAIRFIELD
62 PERRY
63 MORGAN
64 NOBLE
65 MONROE
66 WASHINGTON
67 ATHENS
68 HOCKING
69 VINTON
70 ROSS
71 FAYETTE
72 GREENE
73 MONTGOMERY
74 PREBLE
75 BUTLER
76 WARREN
77 CLINTON
78 HIGHLAND
79 PIKE
80 JACKSON
81 MEIGS
82 GALLIA
83 LAWRENCE
84 SCIOTO
85 ADAMS
86 BROWN
87 CLERMONT
88 HAMILTON

KENTUCKY

1 BOONE
2 KENTON
3 CAMPBELL
4 GREENUP
5 LEWIS
6 MASON
7 [redacted]
8 PENDLETON
9 GRANT
10 GALLATIN
11 CARROLL
12 TRIMBLE
13 OLDHAM
14 HENRY
15 OWEN
16 HARRISON
17 ROBERTSON
18 FLEMING
19 CARTER
20 BOYD
21 LAWRENCE
22 ELLIOTT
23 ROWAN
24 BATH
25 NICHOLAS
26 BOURBON
27 SCOTT
28 FRANKLIN
29 SHELBY
30 JEFFERSON
31 BULLITT
32 SPENCER
33 ANDERSON
34 WOODFORD
35 FAYETTE
36 CLARK
37 MONTGOMERY

NEW YORK

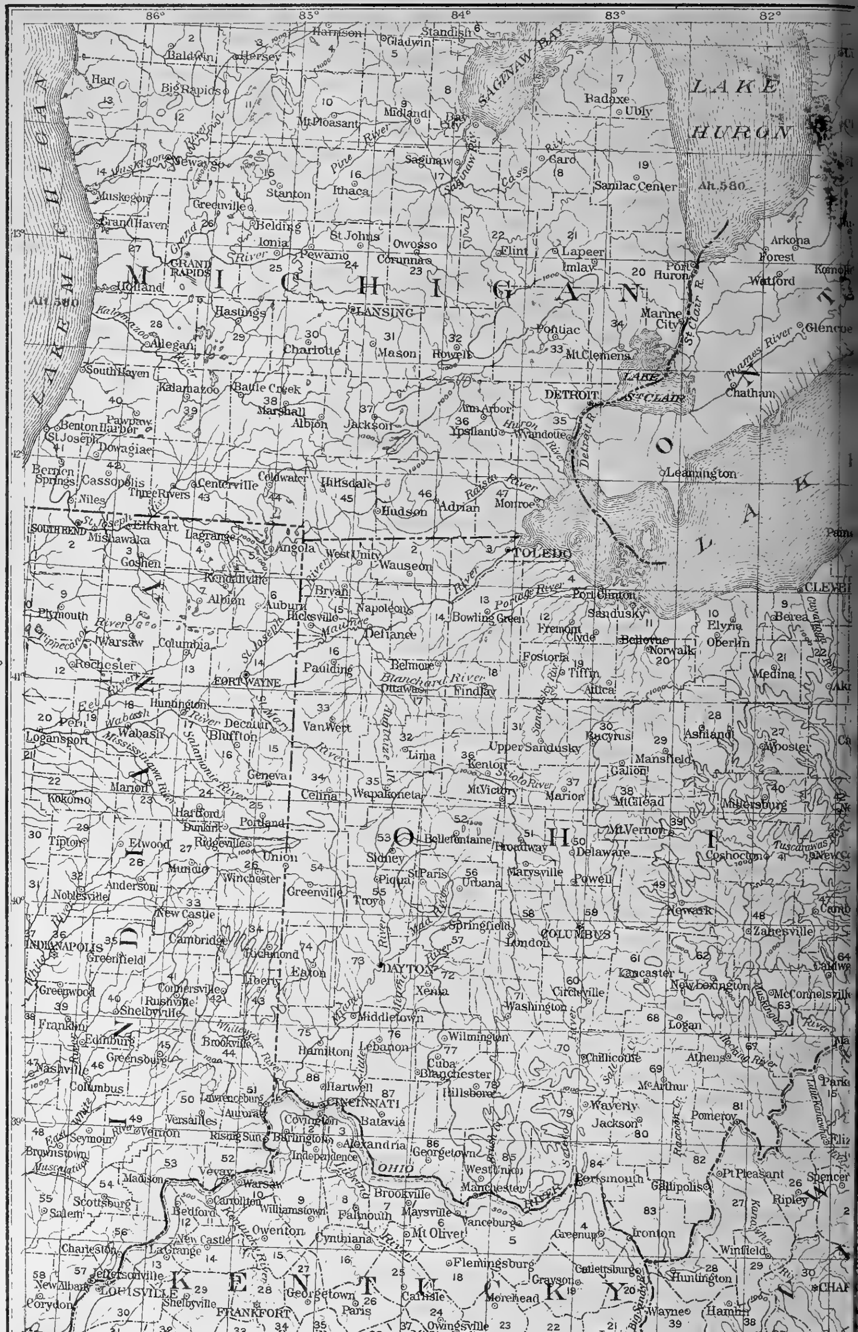
1 JEFFERSON
2 LEWIS
3 ONEIDA
4 OSWEGO
5 CAYUGA
6 WAYNE
7 MONROE
8 ORLEANS
9 NIAGARA
10 ERIE
11 GENESEE
12 WYOMING
13 LIVINGSTON
14 ONTARIO
15 YATES
16 SENECA
17 ONONDAGA
18 MADISON
19 CHENANGO
20 CORTLAND
21 TOMPKINS
22 SCHUYLER
23 BROOME
24 TIOGA
25 CHEMUNG
26 STEUBEN
27 ALLEGANY
28 CATTARAUGUS
29 CHAUTAUQUA

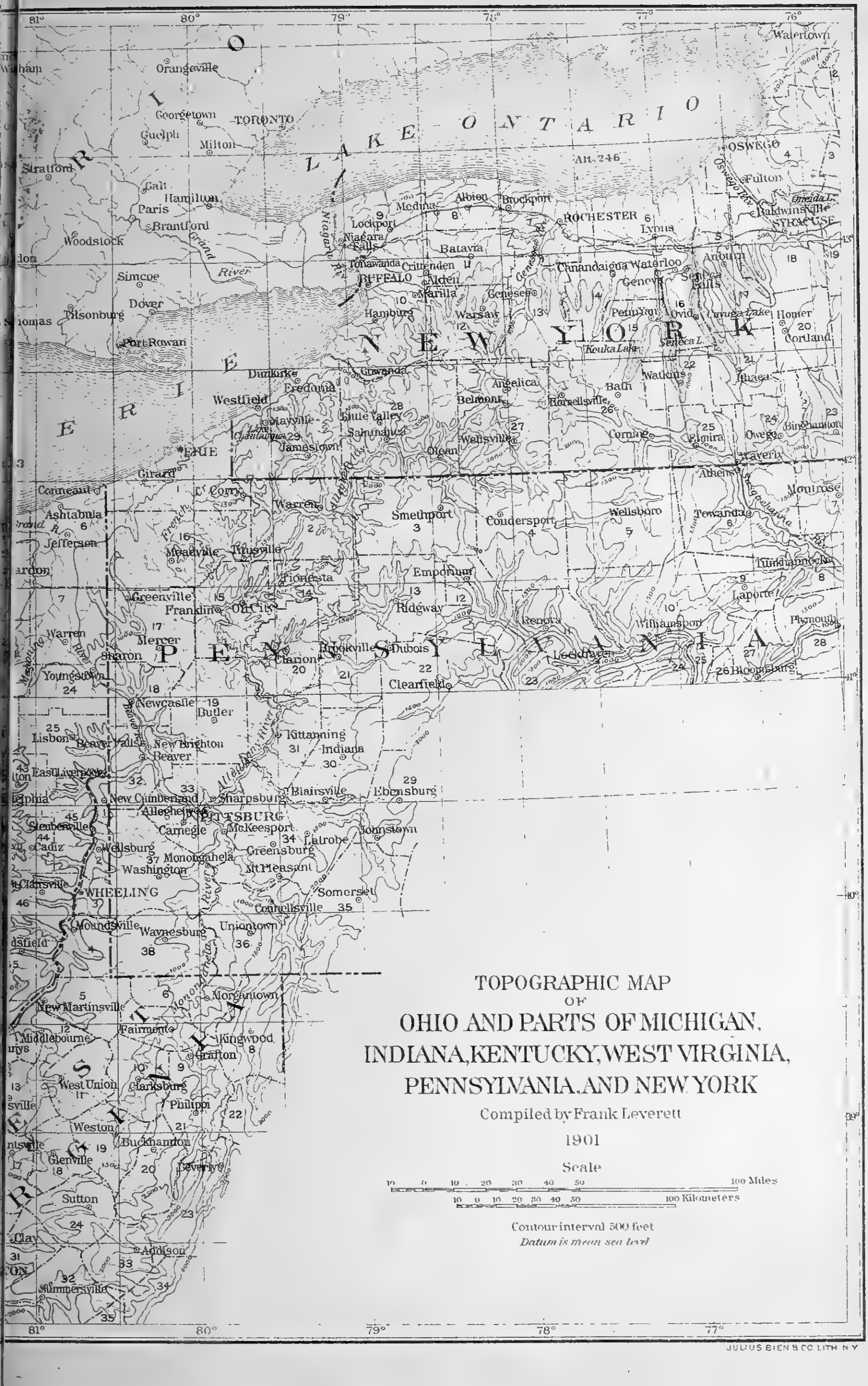
PENNSYLVANIA

1 ERIE
2 WARREN
3 MC.KEAN
4 POTTER
5 TIOGA
6 BRADFORD
7 SUBQUEHANNA
8 WYOMING
9 SULLIVAN
10 LYCOMING
11 CLINTON
12 CAMERON
13 ELK
14 FOREST
15 VENANGO
16 CRAWFORD
17 MERCER
18 LAWRENCE
19 BUTLER
20 CLARION
21 JEFFERSON
22 CLEARFIELD
23 CENTER
24 UNION
25 NORTHUMBERLAND
26 MONTOUR
27 COLUMBIA
28 LUZERNE
29 CAMBRIA
30 INDIANA
31 ARMSTRONG
32 BEAVER
33 ALLEGHENY
34 WESTMORELAND
35 SOMERSET
36 FAYETTE
37 WASHINGTON
38 GREENE

WEST VIRGINIA

1 HANCOCK
2 BROOKE
3 OHIO
4 MARSHALL
5 WETZEL
6 MONONGALIA
7 MARION
8 PRESTON
9 TAYLOR
10 HARRISON
11 DODDRIDGE
12 TYLER
13 RITCHIE
14 PLEASANTS
15 WOOD
16 WIRT
17 CALHOUN
18 GILMER
19 LEWIS
20 UPSHUR
21 BARBOUR
22 TUCKER
23 RANDOLPH
24 BRAXTON
25 ROANE
26 JACKSON
27 MASON
28 CABELL
29 PUTNAM
30 KANAWHA
31 CLAY
32 NICHOLAS
33 WEBSTER
34 POCAHONTAS
35 GREENBRIER
36 FAYETTE
37 BOONE
38 LINCOLN
39 WAYNE





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KENTUCKY
NEW YORK
INDIANA
PENNSYLVANIA
OHIO
WEST VIRGINIA
LAKE HURON
LAKE ONTARIO
LAKE ERIE
LAKE MICHIGAN
TOPOGRAPHIC MAP
OF
OHIO AND PARTS OF MICHIGAN,
INDIANA, KENTUCKY, WEST VIRGINIA,
PENNSYLVANIA, AND NEW YORK
Compiled by Frank Leverett
1901
Scale
Contour interval 500 feet
Datum is mean sea level

GLACIAL FORMATIONS AND DRAINAGE FEATURES OF THE ERIE AND OHIO BASINS.

By Frank Leverett.

CHAPTER I.

INTRODUCTION.

OUTLINE OF THE AREA AND SUBJECTS DISCUSSED.

The region embraced in this discussion has for its northern boundary the south line of Michigan and the southern borders of Lakes Erie and Ontario; for its eastern boundary the Genesee River; for its southeastern and southern boundary the Allegheny and Ohio rivers, except in northern Kentucky, where the southern limits of the drift extend beyond the Ohio River; and for its western boundary the driftless part of southern Indiana.

There is included at the east a system of interlobate moraines lying between the lobe of the Finger Lakes region in New York and the Grand River lobe of northeastern Ohio and the neighboring parts of Pennsylvania and New York, but no discussion of the moraines of the Finger Lakes region is attempted. The deposits and features of the region covered by three glacial lobes of Wisconsin age are described—the Grand River, the Scioto, and the Miami—with the interlobate tracts between, and the valley gravels leading away from these lobes. The older drift lying outside and also beneath the Wisconsin deposits, and the silt deposits which cover this older drift, are also described. In addition to this an attempt is made to interpret some of the drainage features of the region. There is also a discussion of a part of the lake history succeeding the withdrawal of the ice sheet.

This report, like that on the Illinois glacial lobe (Monograph XXXVIII), presents the results of an investigation carried on for several years under the direction of Prof. T. C. Chamberlin, who preceded the writer in a reconnaissance of the region, and has published a preliminary report.[1] To these earlier results, as well as to Chamberlin's direction and suggestions, the writer is greatly indebted.

Indebtedness is also acknowledged to many others who were earlier on the ground, and to many who throughout the investigation have aided by contribution of material and by suggestions concerning the interpretations of the phenomena.

OUTLINE OF PREVIOUS PUBLICATIONS.

It is impracticable to give a full review of the many papers which deal with the surface geology of the region. About 500 of these papers have been examined and an endeavor has been made to duly accredit those which have materially advanced the interpretations. In addition to this a list of all the papers which have come to the writer's notice is presented.

Upon turning to this list the reader will find that Niagara River and its falls and gorge have furnished themes for not fewer than thirty geologists and travelers from the time these striking natural features were first brought to the attention of civilized man in 1535.

The gigantic mammals which once roamed this region, but which are now extinct, furnished a theme for animated discussion at the early meetings of scientific associations in America. The discovery of their bones at Big Bone Lick in Kentucky in 1744 was followed by numerous other discoveries in all parts of the region here described, as well as in other parts of North America. This subject has received less notice in recent years than in the first half of the last century, and the present report has nothing new to offer.

The glacial drift of the region appears to have attracted notice from the earliest days of settlement. This is especially true of Ohio, as shown by the papers of Drake in 1817, of Atwater from 1818 to 1826, of Granger in 1823, of Hildreth from 1827 to 1837, of Darius and Increase Lapham in 1832, of Riddell in 1837, and by the Geological Reports for 1838

[1] Preliminary paper on the terminal moraine of the second Glacial epoch, by T. C. Chamberlin: Third Ann. Rept. U. S. Geol. Survey, 1883, pp. 330-352.

prepared by Mather, Whittlesey, Locke, Foster, and Briggs. Hall and Horsford had given it attention in southwestern New York in 1838 and 1839. As early as 1838 it had become established that the drift extends to the Ohio River in southwestern Ohio, and to the "hill country" of southeastern Ohio. It was also known equally early that it extends to the hilly districts of southern Indiana and southern Illinois. At that date its limits in northwestern Pennsylvania were perhaps less definitely known. Striæ were reported at Sandusky, Ohio, by Granger in 1823; near Lockport and Brockport, N. Y., by Thomas in 1830; near Buffalo, N. Y., by Hayes in 1837; at Rochester, N. Y., by Dewey in the same year; and near Dayton, Ohio, by Locke in the succeeding year.

In explanation of the drift and of the striæ, it seems to have been generally recognized as early as 1839 that currents from the north were the agency of transportation, and that these currents carried large masses of ice which were laden with rock material. It was early recognized that striæ could not be the result of ordinary currents of water. In reference to the striation at Sandusky, Granger remarked in 1823:

The surface is polished as if by friction. It has the appearance of having been formed by the powerful and continued attrition of some hard body. The flutings in depth, width, and direction are as regular as if they had been cut out by some grooving plane. This running water could not effect, nor could its operation have produced, that glossy smoothness which in many parts it still retains.[1]

Locke remarked in 1838, concerning striæ near Dayton, Ohio:

It is impossible to account for the phenomena by supposing them to be the effect of alluvial action. The motion occasioned by a river may wear a surface in general smooth, but not to any extent to a perfect plane. It may roll stones or slide them along, but seldom, if ever, so as to engrave lines so perfectly straight and parallel. I deem it proper here to observe that I did not come to the conclusion that the above-described grooves were ancient or "diluvial grooves" without caution and particular examination.[2]

Dewey remarked, in 1839, concerning striæ in western New York, that they apparently support the glacial theory of Agassiz. He thought, however, that great masses of floating ice might produce the phenomena, and that floods were required to account for the transportation of bowlders across high ridges.[3]

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[1] Am. Jour. Sci., 1st series, Vol. VI, 1823, pp. 179–180.

[2] Second Ann. Rept. Geol. Survey Ohio, 1838, pp. 231–232.

[3] Am. Jour. Sci., 1st series, Vol. XXXVII, 1839, pp. 240–242; idem, 1st series, Vol. XLIV, 1843, pp. 146–150.

By many of the early students the surface bowlders were thought to be a distinct deposit from the sheet of drift which they cover, but some of the earliest writers found them to be a part of that sheet. Thus, Darius and I. A. Lapham noted, in 1832, the occurrence of bowlders in the blue and yellow clays of the "diluvium" near Circleville, Ohio. They remarked also that the rounding of the bowlders is independent of modern stream action.[1]

The effect of the drift on the northern tributaries of the Ohio was early recognized by Drake, who, in 1817, called attention to the fact that the drift terraces are found on northern but not on southern tributaries, and that the northern tributaries have been so filled by the drift that their descent to the Ohio is much more rapid than that of southern tributaries. Drake also discussed, quite clearly for so early a date, the extent of the erratics in the Mississippi Basin, his discussion being based upon his own observations, coupled with those of his friends, Nuttall, Goforth, and Warren. The agent of transportation is thought by him to have been icebergs.[2]

Among other early papers worthy of special mention is one by J. T. Plummer, of Richmond, Ind., which contains a lucid description of striæ and drift in the vicinity of that city.[3] Several papers by Whittlesey are full of important data, among which may be mentioned Notes on the Drift of Ohio and the West,[4] Fresh Water Glacial Drift of the Northwestern States,[5] and Ice Movements in the St. Lawrence Valley.[6] Alfred T. King presented a brief but discriminating discussion of the Ancient Alluvium of the Ohio and Tributaries in an early volume of the Philadelphia Academy of Sciences.[7] O. N. Stoddard early called attention to a bowlder pavement in Ohio and urged it as evidence of glacial action.[8]

E. B. Andrews discussed the relation of the river terraces of southern Ohio to drift theories, and held that they were glacial dependencies, rather

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[1] Am. Jour. Sci., 1st series, Vol. XXII, 1832, pp. 300–303.

[2] Paper read before the American Philosophical Society in 1818; published in Trans. Am. Philos. Soc., new series, Vol. II, 1825, pp. 124–139.

[3] Am. Jour. Sci., 1st series, Vol. XLIV, 1843, pp. 281–315.

[4] Idem, 2d series, Vol. V, 1843, pp. 205–217.

[5] Smithsonian Contrib., Vol. XV., 1867, 32 pages.

[6] Proc. Am. Assoc. Adv. Sci., Vol. XV, 1867, pp. 43–54.

[7] Proc. Phila. Acad. Sci., Vol. VII, 1856, pp. 4–8.

[8] Am. Jour. Sci., 2d series, Vol. XXVIII., 1859, pp. 227–228.

than marine or lacustrine.[1] He called attention also to the fact that the termination of the drift is on a southward-sloping country and that its distribution is consistent only with the glacial hypothesis.

The drift and drainage features were given only incidental notice in the first geological surveys of Ohio and Pennsylvania, and but limited attention by the New York survey. The second geological survey of Ohio, organized in 1869 under Newberry, has given, in the reports for each county, a brief discussion of these features. In addition to this, Newberry presented, in Volume II of the Geology of Ohio, a special discussion of surface geology, covering about 80 pages, in which the principal facts scattered through Volumes I and II are brought together and interpreted. The data collected by that survey are discussed in some detail in the body of this report in connection with those collected subsequently by the writer and others.

The second geological survey of Pennsylvania, under the direction of Lesley, collected in the decade beginning in 1875 many facts bearing on the drift and drainage features of northwestern Pennsylvania. These appear in connection with the study of the underlying rock formations in Reports I^2, I^3, and I^4, prepared by Carll; in K, KK, and KKK, by Stevenson; in Q, QQ, Q^3, and Q^4, by White; and in VV, by Chance. In addition to these, a special study of the glacial boundary in Pennsylvania and southwestern New York was made in 1882 by Lewis, with the assistance of G. F. Wright, which forms Report Z of the Pennsylvania survey. The data thus collected are more carefully noted in the body of this report.

The mapping of the glacial boundary was continued by Wright across Ohio and northern Kentucky under the auspices of the Western Reserve Historical Society of Cleveland, Ohio, and across Indiana and Illinois under the present Survey. The results of the former study appeared in a bulletin of the society, while the main results of the entire study are presented in Bulletin 58 of this Survey. Wright has also incorporated this material in his Ice Age in North America, while special topics connected with these and other studies have been discussed by him in various scientific journals. The mapping by Wright is found to apply in northwestern Pennsylvania and eastern and central Ohio chiefly to the border of the Wisconsin drift, but in southwestern Ohio and districts farther west it indicates the approximate

[1] Proc. Am. Assoc. Adv. Sci., Vol. XIII, 1860, pp. 319–321.

border of the older drift. In portions of central Ohio and northwestern Pennsylvania the older drift extends several miles beyond the limits of the Wisconsin, and thus invalidates the use of the term glacial boundary for portions of the line traced by Lewis and Wright, since it was not on the boundary. The name terminal moraine, however, is more pertinent to this portion, since it is the Wisconsin terminal moraine.

Within the portion of Indiana under discussion much attention has been given by the Indiana geological survey to the drift of the northeastern counties, which are reported upon by Dryer, and to a few counties in the eastern and southeastern portions, reported upon by Phinney, McCaslin, Elrod, Warder, and Borden. The reports of Dryer and Phinney have given due attention to moraines and other drift forms, and are notably in harmony with present methods of classification. Each of the other reports also contains valuable data.

The preliminary report by Chamberlin, referred to above, deals chiefly with a strong morainic system which he traced from Wisconsin southeastward into Indiana and thence eastward into New York, and found to be disposed in loops around the western and southern ends of the great basins of the region. In this and subsequent papers Chamberlin has sought to discriminate between drift sheets of different ages and to determine the several stages of the Glacial epoch.

Aside from the reports and papers already mentioned there are several papers by Chamberlin, Claypole, Dryer, Fairchild, Foshay, Hice, Spencer, Taylor, Tight, Upham, White, Wright, and others, which throw light on the glacial history of this region, as shown in the course of the discussion. For titles and places of publication of these and other papers bearing upon the region the subjoined list may be consulted:

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OUTLINE OF TIME RELATIONS, OR GLACIAL SUCCESSION.

This outline is essentially the same as the writer's outline presented in Monograph XXXVIII, the only important modification being in the subdivisions of the late Wisconsin glacial stage. These are more complete in the Ohio district than in the Illinois, and require a corresponding elaboration of the outline.

In the progress of the study of the glacial deposits the complexity of the glacial history has been gradually unfolded. After the abandonment of the iceberg hypothesis, the early students approached the study with the hypothesis of a single and practically continuous period of drift deposition, in which the ice sheet at one time covered the entire glaciated area. This period was supposed to have terminated with a single high stage of water, attending the melting of the ice, which was termed the Champlain epoch. But it soon became apparent that this simple hypothesis could not be made to cover the complex glacial history. Evidences of a complicated succession of recessions and advances of the ice sheet were recognized, and a sharp controversy arose concerning the importance of these oscillations. It was held by some students that they are of minor importance, and mark short or partial retreats and advances in a single epoch of glaciation; while others contended for the necessity of recognizing two or more ice invasions, between which there were extensive and prolonged deglaciation intervals.

The studies upon which the present report is based, as well as those of the earlier report,[1] have developed evidence which, in connection with other evidence gathered in various parts of the glacial field in this country and in Europe, is thought to have a decisive bearing upon the question. The evidences of prolonged intervals of deglaciation are strong and have been decidedly increased by the progress of critical study.

The several sheets of glacial drift in this and neighboring regions have received geographic names, as have also some of the interglacial beds. Names of this class were proposed by Chamberlin a few years since as a substitute for the time phrases which had arisen and which were of controverted application.[2] As these names represent only the main divisions of the Glacial epoch, others are necessary to denote the subdivisions. In the report on the Illinois glacial lobe, and in the present report, several names are thus introduced to designate the moraines and their associated sheets of drift. These names are usually selected from towns located on the moraines or from streams whose courses are governed by the moraines. In most cases they have come into use in the office and in correspondence with other glacialists, as a convenient form of reference. The selection of names thus made seems suitable for general use.

The outline given below aims to cover the events between the deposition of the oldest recognized drift sheet and the final recession of the ice sheet into the region north of the Great Lakes. The main divisions appear to be much longer than the secondary ones. The latter are not thought to be marked by intervals sufficiently prolonged to merit the application of the term epoch. It is probable, however, as shown further on, that some oscillations of the ice front occurred, so that the moraines on which these subdivisions are based do not mark simply halts in the recession of the ice.

OUTLINE OF DRIFT SHEETS AND INTERVALS.

1. Oldest recognized drift sheet, the sub-Aftonian of Chamberlin, and perhaps the Albertan of Dawson.
2. First interval of deglaciation; Aftonian of Chamberlin.
3. Kansan drift sheet of the Iowa geologists.

[1] The Illinois Glacial Lobe, Mon. U. S. Geol. Survey, Vol. XXXVIII.

[2] See Geikie's Great Ice Age, third edition, 1894, pp. 754–774. See also Jour. Geol., Vol. III, pp. 270–277, and Vol. IV, pp. 872–876.

MICHIGAN

1 MASON
2 LAKE
3 OSCEOLA
4 CLARE
5 GLADWIN
6 ARENAC
7 HURON
8 BAY
9 MIDLAND
10 ISABELLA
11 MECOSTA
12 NEWAYGO
13 OCEANA
14 MUSKEGON
15 MONTCALM
16 GRATIOT
17 SAGINAW
18 TUSCOLA
19 SANILAC
20 ST CLAIR
21 LAPEER
22 GENESEE
23 SHIAWASSEE
24 CLINTON
25 IONIA
26 KENT
27 OTTAWA
28 ALLEGAN
29 BARRY
30 EATON
31 INGHAM
32 LIVINGSTON
33 OAKLAND
34 MACOMB
35 WAYNE
36 WASHTENAW
37 JACKSON
38 CALHOUN
39 KALAMAZOO
40 VAN BUREN
41 BERRIEN
42 CASS
43 ST.JOSEPH
44 BRANCH
45 HILLSDALE
46 LENAWEE
47 MONROE

INDIANA

1 LAPORTE
2 ST.JOSEPH
3 ELKHART
4 LAGRANGE
5 STEUBEN
6 DEKALB
7 NOBLE
8 KOSCIUSKO
9 MARSHALL
10 STARKE
11 PULASKI
12 FULTON
13 WHITLEY
14 ALLEN
15 ADAMS
16 WELLS
17 HUNTINGTON
18 WABASH
19 MIAMI
20 CASS
21 CARROLL
22 HOWARD
23 GRANT
24 BLACKFORD
25 JAY
26 RANDOLPH
27 DELAWARE
28 MADISON
29 TIPTON
30 CLINTON
31 BOONE
32 HAMILTON
33 HENRY
34 WAYNE
35 HANCOCK
36 MARION
37 HENDRICKS
38 MORGAN
39 JOHNSON
40 SHELBY
41 RUSH
42 FAYETTE
43 UNION
44 FRANKLIN
45 DECATUR
46 BARTHOLOMEW
47 BROWN
48 JACKSON
49 JENNINGS
50 RIPLEY
51 DEARBORN
52 SWITZERLAND
53 JEFFERSON
54 SCOTT
55 WASHINGTON
56 CLARK
57 FLOYD
58 HARRISON

OHIO

1 WILLIAMS
2 FULTON
3 LUCAS
4 OTTAWA
5 LAKE
6 ASHTABULA
7 TRUMBULL
8 GEAUGA
9 CUYAHOGA
10 LORAIN
11 ERIE
12 SANDUSKY
13 WOOD
14 HENRY
15 DEFIANCE
16 PAULDING
17 PUTNAM
18 HANCOCK
19 SENECA
20 HURON
21 MEDINA
22 SUMMIT
23 PORTAGE
24 MAHONING
25 COLUMBIANA
26 STARK
27 WAYNE
28 ASHLAND
29 RICHLAND
30 CRAWFORD
31 WYANDOT
32 ALLEN
33 VAN WERT
34 MERCER
35 AUGLAIZE
36 HARDIN
37 MARION
38 MORROW
39 KNOX
40 HOLMES
41 COSHOCTON
42 TUSCARAWAS
43 CARROLL
44 HARRISON
45 JEFFERSON
46 BELMONT
47 GUERNSEY
48 MUSKINGUM
49 LICKING
50 DELAWARE
51 UNION
52 LOGAN
53 SHELBY
54 DARKE
55 MIAMI
56 CHAMPAIGN
57 CLARK
58 MADISON
59 FRANKLIN
60 PICKAWAY
61 FAIRFIELD
62 PERRY
63 MORGAN
64 NOBLE
65 MONROE
66 WASHINGTON
67 ATHENS
68 HOCKING
69 VINTON
70 ROSS
71 FAYETTE
72 GREENE
73 MONTGOMERY
74 PREBLE
75 BUTLER
76 WARREN
77 CLINTON
78 HIGHLAND
79 PIKE
80 JACKSON
81 MEIGS
82 GALLIA
83 LAWRENCE
84 SCIOTO
85 ADAMS
86 BROWN
87 CLERMONT
88 HAMILTON

KENTUCKY

1 BOONE
2 KENTON
3 CAMPBELL
4 GREENUP
5 LEWIS
6 MASON
7 BRACKEN
8 PENDLETON
9 GRANT
10 GALLATIN
11 CARROLL
12 TRIMBLE
13 OLDHAM
14 HENRY
15 OWEN
16 HARRISON
17 ROBERTSON
18 FLEMING
19 CARTER
20 BOYD
21 LAWRENCE
22 ELLIOTT
23 ROWAN
24 BATH
25 NICHOLAS
26 BOURBON
27 SCOTT
28 FRANKLIN
29 SHELBY
30 JEFFERSON
31 BULLITT
32 SPENCER
33 ANDERSON
34 WOODFORD
35 FAYETTE
36 CLARK
37 MONTGOMERY

NEW YORK

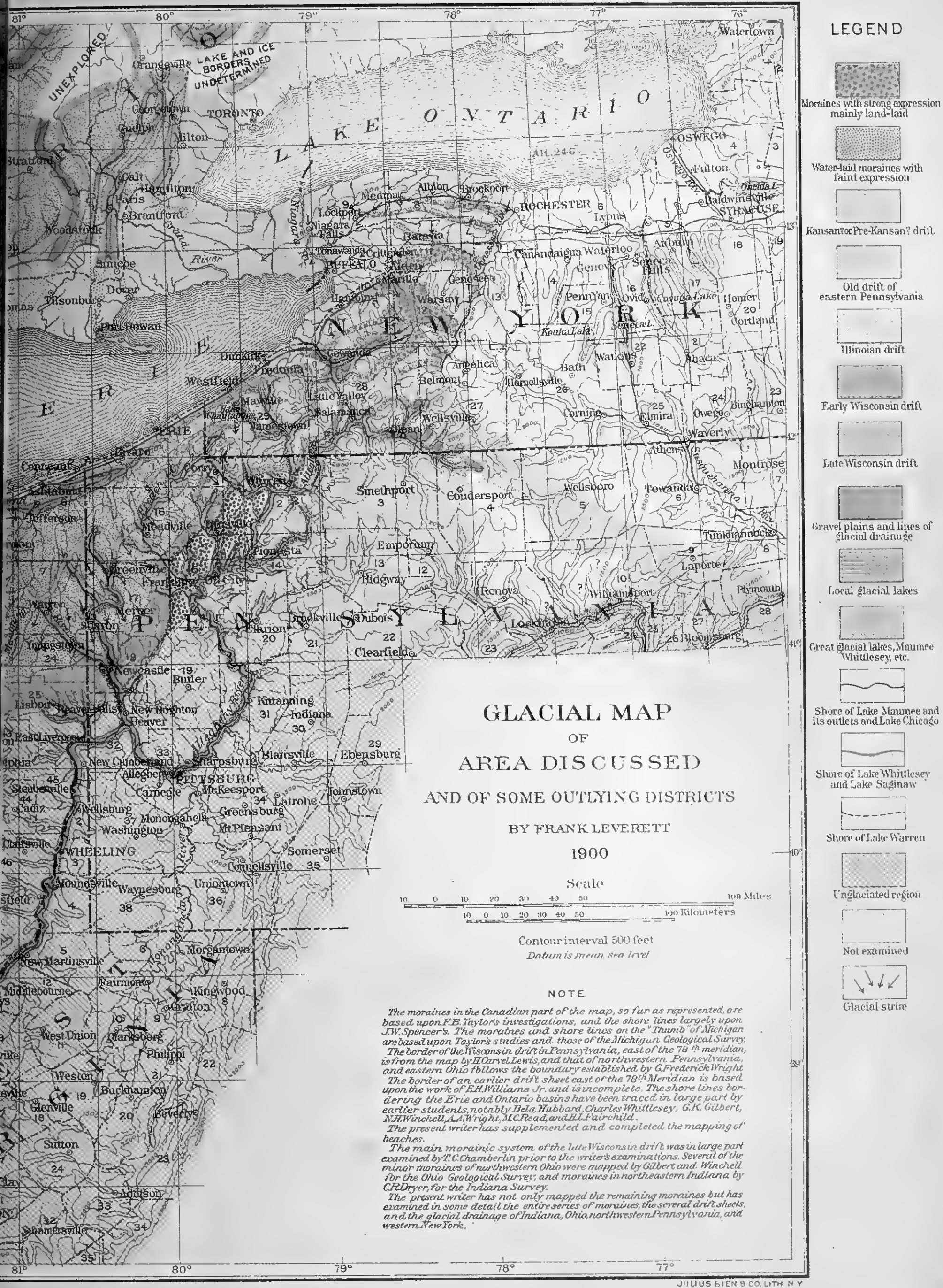
1 JEFFERSON
2 LEWIS
3 ONEIDA
4 OSWEGO
5 CAYUGA
6 WAYNE
7 MONROE
8 ORLEANS
9 NIAGARA
10 ERIE
11 GENESEE
12 WYOMING
13 LIVINGSTON
14 ONTARIO
15 YATES
16 SENECA
17 ONONDAGA
18 MADISON
19 CHENANGO
20 CORTLAND
21 TOMPKINS
22 SCHUYLER
23 BROOME
24 TIOGA
25 CHEMUNG
26 STEUBEN
27 ALLEGANY
28 CATTARAUGUS
29 CHAUTAUQUA

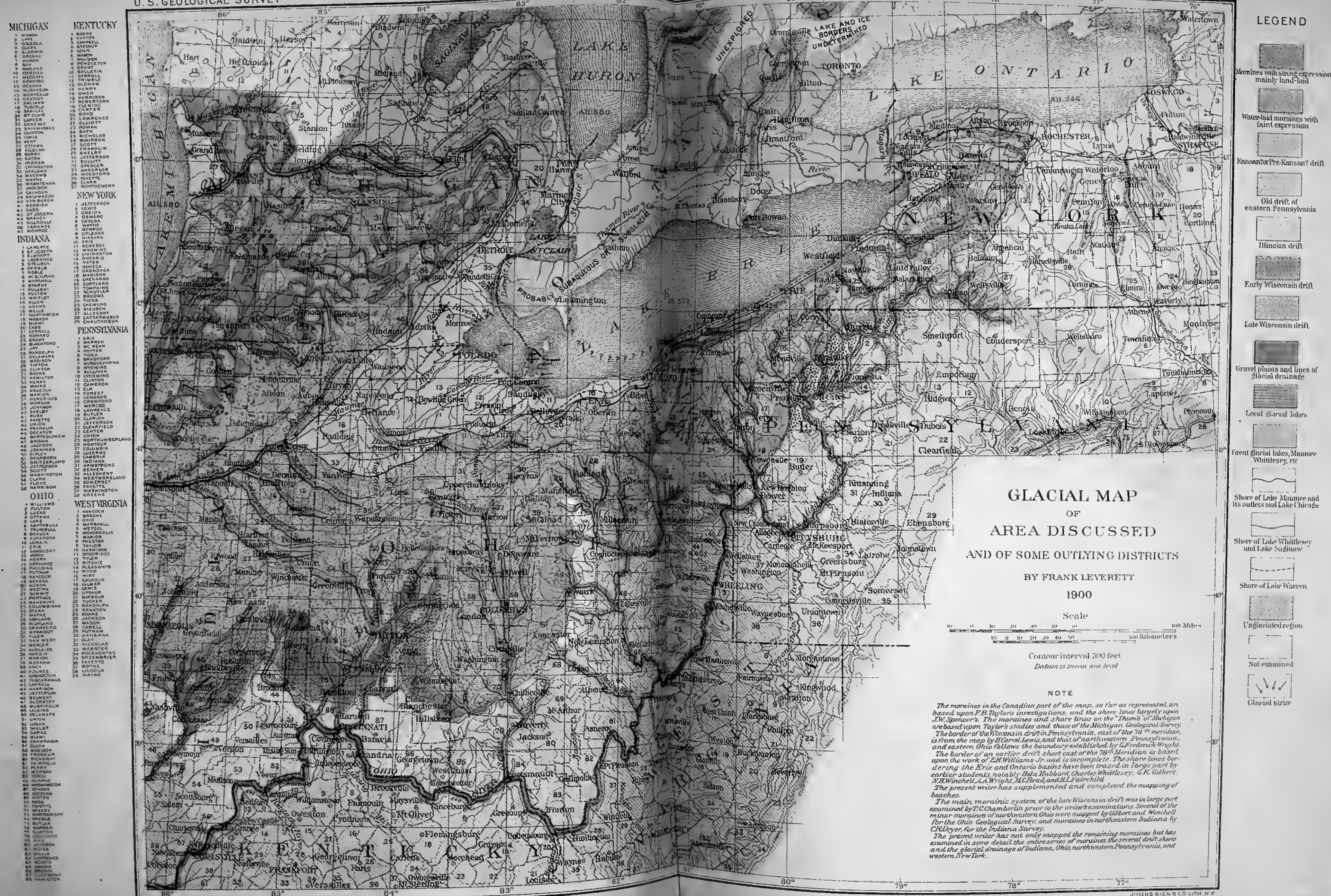
PENNSYLVANIA

1 ERIE
2 WARREN
3 MC.KEAN
4 POTTER
5 TIOGA
6 BRADFORD
7 SUSQUEHANNA
8 WYOMING
9 SULLIVAN
10 LYCOMING
11 CLINTON
12 CAMERON
13 ELK
14 FOREST
15 VENANGO
16 CRAWFORD
17 MERCER
18 LAWRENCE
19 BUTLER
20 CLARION
21 JEFFERSON
22 CLEARFIELD
23 CENTER
24 UNION
25 NORTHUMBERLAND
26 MONTOUR
27 COLUMBIA
28 LUZERNE
29 CAMBRIA
30 INDIANA
31 ARMSTRONG
32 BEAVER
33 ALLEGHENY
34 WESTMORELAND
35 SOMERSET
36 FAYETTE
37 WASHINGTON
38 GREENE

WEST VIRGINIA

1 HANCOCK
2 BROOKE
3 OHIO
4 MARSHALL
5 WETZEL
6 MONONGALIA
7 MARION
8 PRESTON
9 TAYLOR
10 HARRISON
11 DODDRIDGE
12 TYLER
13 RITCHIE
14 PLEASANTS
15 WOOD
16 WIRT
17 CALHOUN
18 GILMER
19 LEWIS
20 UPSHUR
21 BARBOUR
22 TUCKER
23 RANDOLPH
24 BRAXTON
25 ROANE
26 JACKSON
27 MASON
28 CABELL
29 PUTNAM
30 KANAWHA
31 CLAY
32 NICHOLAS
33 WEBSTER
34 POCAHONTAS
35 GREENBRIER
36 FAYETTE
37 BOONE
38 LINCOLN
39 WAYNE


GLACIAL MAP
OF
AREA DISCUSSED
AND OF SOME OUTLYING DISTRICTS
BY FRANK LEVERETT
1900
Scale
100 Miles
100 Kilometers
Contour interval 500 feet
Datum is mean sea level
NOTE
The moraines in the Canadian part of the map, so far as represented, are based upon F.B.Taylor's investigations, and the shore lines largely upon J.W.Spencer's. The moraines and shore lines on the "Thumb" of Michigan are based upon Taylor's studies and those of the Michigan Geological Survey.
The border of the Wisconsin drift in Pennsylvania, east of the 78th meridian, is from the map by H.Carvel Lewis, and that of northwestern Pennsylvania, and eastern Ohio follows the boundary established by G.Frederick Wright
The border of an earlier drift sheet east of the 78th Meridian is based upon the work of E.H.Williams Jr. and is incomplete. The shore lines bordering the Erie and Ontario basins have been traced in large part by earlier students, notably Bela Hubbard, Charles Whittlesey, G.K. Gilbert, N.H.Winchell, A.A.Wright, M.C.Read, and H.L.Fairchild.
The present writer has supplemented and completed the mapping of beaches.
The main morainic system of the late Wisconsin drift was in large part examined by T.C.Chamberlin prior to the writer's examinations. Several of the minor moraines of northwestern Ohio were mapped by Gilbert and Winchell for the Ohio Geological Survey, and moraines in northeastern Indiana by C.R.Dryer, for the Indiana Survey.
The present writer has not only mapped the remaining moraines but has examined in some detail the entire series of moraines, the several drift sheets, and the glacial drainage of Indiana, Ohio, northwestern Pennsylvania, and western New York.
LAKE ONTARIO
LAKE ERIE
NEW YORK
PENNSYLVANIA
WEST VIRGINIA
LAKE AND ICE BORDERS UNDETERMINED
UNEXPLORED
TORONTO
ROCHESTER
BUFFALO
SYRACUSE
PITTSBURG
WHEELING
ERIE
OSWEGO
LEGEND
Moraines with strong expression mainly land-laid
Water-laid moraines with faint expression
Kansan? or Pre-Kansan? drift
Old drift of eastern Pennsylvania
Illinoian drift
Early Wisconsin drift
Late Wisconsin drift
Gravel plains and lines of glacial drainage
Local glacial lakes
Great glacial lakes, Maumee Whittlesey, etc.
Shore of Lake Maumee and its outlets and Lake Chicago
Shore of Lake Whittlesey and Lake Saginaw
Shore of Lake Warren
Unglaciated region
Not examined
Glacial striæ


MICHIGAN
KENTUCKY
INDIANA
NEW YORK
PENNSYLVANIA
OHIO
WEST VIRGINIA
LAKE HURON
LAKE ONTARIO
LAKE ERIE
LAKE MICHIGAN
MICHIGAN
NEW YORK
PENNSYLVANIA
OHIO
KENTUCKY
LAKE AND ICE BORDERS UNDETERMINED
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Moraines with strong expression mainly land-laid
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Gravel plains and lines of glacial drainage
Local glacial lakes
Great glacial lakes, Maumee Whittlesey, etc
Shore of Lake Maumee and its outlets and Lake Chicago
Shore of Lake Whittlesey and Lake Saginaw
Shore of Lake Warren
Unglaciated region
Not examined
Glacial striæ
GLACIAL MAP
OF
AREA DISCUSSED
AND OF SOME OUTLYING DISTRICTS
BY FRANK LEVERETT
1900
Scale
100 Miles
100 Kilometers
Contour interval 500 feet
Datum is mean sea level
NOTE
The moraines in the Canadian part of the map, so far as represented, are based upon F.B.Taylor's investigations, and the shore lines largely upon J.W.Spencer's. The moraines and shore lines on the "Thumb" of Michigan are based upon Taylor's studies and those of the Michigan Geological Survey.
The border of the Wisconsin drift in Pennsylvania, east of the 78th meridian, is from the map by H.Carvel Lewis, and that of northwestern Pennsylvania, and eastern Ohio follows the boundary established by G.Frederick Wright.
The border of an earlier drift sheet east of the 78th Meridian is based upon the work of E.H.Williams Jr. and is incomplete. The shore lines bordering the Erie and Ontario basins have been traced in large part by earlier students, notably Bela Hubbard, Charles Whittlesey, G.K.Gilbert, N.H.Winchell, A.A.Wright, M.C.Read, and H.L.Fairchild.
The present writer has supplemented and completed the mapping of beaches.
The main morainic system of the late Wisconsin drift was in large part examined by T.C.Chamberlin prior to the writer's examinations. Several of the minor moraines of northwestern Ohio were mapped by Gilbert and Winchell for the Ohio Geological Survey, and moraines in northeastern Indiana by C.R.Dryer, for the Indiana Survey.
The present writer has not only mapped the remaining moraines but has examined in some detail the entire series of moraines, the several drift sheets and the glacial drainage of Indiana, Ohio, northwestern Pennsylvania, and western New York.
JULIUS BIEN & CO. LITH. N.Y.

4. Second or Yarmouth interval of recession or deglaciation.
5. Illinoian drift sheet.
6. Third or Sangamon interval of recession or deglaciation.
7. Iowan drift sheet and main loess deposit.
8. Fourth or Peorian interval of recession or deglaciation.
9. Early Wisconsin drift sheets, as represented in Illinois, the display in the Ohio district being less complete.
    - *a.* Shelbyville morainic system.
    - *b.* Champaign morainic system.
    - *c.* Bloomington morainic system.
    - *d.* Marseilles morainic system.
10. Fifth interval of recession (unnamed), shown by shifting of ice lobes.
11. Late Wisconsin drift sheet, as represented in the Ohio district.
    - *a.* The main morainic system and attendant great bowlder belts.
    - *b.* Mississinawa (Valparaiso?) morainic system; includes Union and Mississinawa moraines of the Maumee-Miami lobe and the Powell and Broadway moraines of the Scioto lobe, and is a probable correlative of the Valparaiso morainic system of the Lake Michigan lobe.
    - *c.* St. Johns or Salamonie moraine.
    - *d.* Wabash moraine.
    - *e.* St. Marys or Fort Wayne moraine.
    - *f.* Lake Maumee beaches and correlative moraines.
    - *g.* Lake Whittlesey beach and correlative moraines.
    - *h.* Lake Warren beaches and correlative moraines.
    - *i.* Lake Dana beach (Lake Lundy?).
    - *j.* Lake Iroquois beach.

By reference to the glacial map, Pl. II, the extent of exposure of each till sheet and the distribution of the moraines and the lake beaches may be seen. It will be observed that the oldest drift sheet of this region (the Kansan or pre-Kansan) is exposed only in a limited area in northwestern Pennsylvania. The next younger or Illinoian drift sheet has not been recognized in northwestern Pennsylvania, but it is extensively exposed in southwestern Ohio, southeastern Indiana, and in the glaciated portion of Kentucky. The Iowan drift sheet appears not to extend beyond the limits of the Wisconsin drift in the region covered by the map, but a silt deposit which appears to

be of Iowan age covers the Illinoian drift and extends beyond it into the unglaciated district to an undetermined distance. The early Wisconsin drift is exposed outside the limits of the late Wisconsin in southeastern Indiana and southwestern Ohio, and may perhaps be represented in the southern portion of the drift east of the reentrant angle in the glacial boundary in western New York. But in central and eastern Ohio and in northwestern Pennsylvania it occurs to but a limited extent, if at all, outside the late Wisconsin. The late Wisconsin drift covers a large part of the glaciated portion of this region. The distribution of its several moraines is indicated on the glacial map. The extent of the great glacial lakes, Maumee, Whittlesey, and Warren, is shown in Pls. XX, XXI, XXIII, and XXVI more clearly than in the glacial map. As the several drift sheets, the moraines, and the beaches are discussed in detail farther on, they may be left here with this passing reference.

OUTLINE OF ROCK FORMATIONS.

Inasmuch as the topographic features of this region depend largely upon the character of its rock formations, a brief outline of the distribution and characteristics of each of the formations here represented seems necessary. Some difficulty is found in the correlation and grouping of certain formations because of the variations which they display when carried over so large a region, and also because of the uncertainty as to exact equivalency where outcrops occur only in widely separated districts. In some cases a formation whose equivalency is well established has a constitution that is quite unlike its constitution in the type locality. In other cases a similar constitution is found in widely separated areas, but the equivalency has not been fully established. The classification of the Ohio rock series presented by Orton in a recent report of this Survey[1] and in the last volume of the Ohio survey[2] is based upon a careful comparison of the Ohio series with those of New York and Pennsylvania, where most of the type localities occur. It is, however, designed only for Ohio, and needs to be supplemented in the wider region embraced in the present report.

The arrangement of the formations is quite simple, the only axes of

[1] The rock waters of Ohio, by Edward Orton: Nineteenth Ann. Rept. U. S. Geol. Survey, Pt. IV, Hydrography, 1898, pp. 638–650.

[2] The geological scale of Ohio, by Edward Orton: Geology of Ohio, Vol. VII, 1894, pp. 3–44.

disturbance that have sufficient prominence to affect seriously the distribution of the rock formations being the Cincinnati arch with its western and eastern branches. Along its broad, flat-topped crest the oldest formations of Ohio and Indiana are exposed. The strata dip westward from the arch and its western arm toward the coal basin of Indiana and Illinois, while between the arms they dip northward toward the coal basin of Michigan. From the borders of Lakes Ontario and Erie the strata dip southward and southeastward to the coal basin of the Allegheny Plateau, while from the Cincinnati arch they dip eastward toward the same basin. In passing toward the coal basins either from the Cincinnati arch and its branches or from the north border of the region, a succession of rock formations is encountered which have an imbricate arrangement, and the outcrops present an ascending series in the geological scale. The series embraces that part of the geological time scale which falls between the Trenton epoch of the Lower Silurian or Ordovician and the Permian epoch of the Carboniferous. It includes the groups of rocks set forth in the following series, which are given in their order of development from older to newer.

Table of rock formations.

Silurian	Lower (Ordovician)	Trenton limestone.
		Utica shale.
		Hudson River group.
	Upper	Medina group.
		Clinton group.
		Niagara group.
		Salina and Waterlime.
		Lower Helderberg limestone.
Devonian		Oriskany sandstone.
		Corniferous limestone.
		Marcellus shale and Hamilton formation.
		Genesee, Portage, and Chemung, or Ohio shale.
Classification unsettled		Waverly or Bedford shale (Catskill?).
		Berea grit and shale (Catskill?).
Carboniferous		Cuyahoga shale (equivalent of part of Pocono sandstone).
		Logan conglomerate (equivalent of part of Pocono sandstone).
		Pottsville, or Conglomerate Coal Measures.
		Allegheny, or Lower Productive Coal Measures.
		Conemaugh, or Lower Barren Coal Measures.
		Monongahela, or Upper Productive Coal Measures.
		Dunkard beds (Permian?).

Trenton limestone and Utica shale.—The two lower members of the above series, although clearly represented in a large part of this region beneath later rock

formations, are not known certainly to have outcrops, and will therefore be passed by without further description.

Hudson River group.—The Hudson River group, as described in the Indiana and Ohio reports, consists of alternating beds of limestone and shale. Its outcrop covers about 4,000 square miles in Ohio, 1,800 square miles in southeastern Indiana, and also a large area in the adjacent part of Kentucky. Its outcrops in the three States embrace the central part of the Cincinnati arch.

The crown of the arch, capped as it is by the soft and friable rocks of this group, has suffered greater reduction than the slopes. Much of it is slightly lower than the portion of the slopes capped by the resistant Lockport (Niagara) limestone.

Medina group.—The Medina group outcrops extensively along the south border of Lake Ontario in western New York. It has only a limited outcrop in Indiana and Ohio, on the borders of the Hudson River outcrop. In Indiana and western Ohio the Medina is almost entirely a shale formation, but in eastern Ohio and farther east sandstones are interbedded with the shale. The heaviest beds in New York are shales, but there are also resistant sandstones of considerable thickness. This formation has usually a reddish color, both as shale and as sandstone. The part taken by the Medina sandstone in forming the waterfalls in western New York is discussed farther on.

Clinton group.—The Clinton limestone outcrops in western New York immediately south of the outcrop of the Medina. In Ohio and Indiana it is restricted, like the Medina, to a narrow strip on the margin of the outcrop of the Hudson River group. The most characteristic stratum is a firm limestone, but the drill has shown that in parts of Ohio it is a sandstone, while in eastern Ohio it becomes shaly. In New York it is a limestone with ferruginous bands. In New York and to some extent in Indiana and Ohio it has produced waterfalls in connection with the underlying shaly beds of the Medina group.

Niagara group.—The outcrop of the Niagara group in western New York is a narrow strip leading eastward from the Niagara River to the vicinity of Utica. It forms a conspicuous part of the Niagara Falls and the gorge below the falls, as well as other falls and gorges in western New York. The name Niagara was given because of the outcrops on the Niagara River. The group is divided into two formations. The main member is the Lockport

limestone.[1] Beneath this is the Rochester shale,[1] which includes the Dayton building stone.

The Niagara group covers in its outcrops or as a surface rock not less than 5,000 square miles in western Ohio. The main area of outcrop is immediately north and east of the area of the Hudson River group. But there are extensive outcrops farther north in a belt leading from Hardin County northward to the western end of Lake Erie. In Indiana the group appears as the surface rock in an area of fully 5,000 square miles along the north and west borders of the area of the Hudson River group. There is a small area of outcrop in the northwestern part of the State, but that lies outside the region under discussion. A considerable area in northern Kentucky, contiguous to the areas of Indiana and Ohio, also lies outside this region.

Salina and Waterlime, or the Onondaga series.—These two somewhat unlike formations have been referred by Hall, Dana, and others to a single geological epoch, the Onondaga. The outcrop of the Salina formation in New York covers a narrow belt leading eastward from Grand Island in Niagara River to the Hudson River Valley. Its thickness in the eastern part of the State is only 100 to 200 feet, but in Onondaga County, in central New York, it reaches a thickness of 800 feet and continues thick from that locality westward. Like the Hudson River group, it consists largely of soft rocks, shales, and shaly limestone, with marls and beds or veins of gypsum. As a result of its soft texture the area of outcrop of this formation has become the site of a shallow basin. The Waterlime formation in western New York rests upon the Salina without a perceptible break or line of demarcation. It consists of an impure silico-argillaceous limestone, which is more enduring than the remainder of the salt group and can be distinctly traced through the district.

Orton considers it doubtful whether the Salina beds occur in the Ohio rock series. The Waterlime outcrops extensively in northwestern Ohio and also in the north-central part of the State, its outcrops being about as extensive as those of the Niagara group. It is in the main a compact magnesian limestone of drab or brown color.

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[1] The Lockport limestone and the Rochester shale were formerly called the Niagara limestone and the Niagara shale, but by the usage of the United States Geological Survey the term Niagara is now applied only to the group or higher classific unit.

The equivalent of this group in Indiana occurs as the surface rock in a narrow strip on the north and northwest border of the Niagara area north of Indianapolis; also in a small tract in the vicinity of Logansport, and, as interpreted by Phinney, in a considerable area in the northwestern part of the State. The exposures in Indiana are few on account of the great thickness of the drift. This is also the case in much of the Ohio area.

Lower Helderberg limestone.—The Lower Helderberg has been separated from the Waterlime in New York and in Indiana, but was classed with it by Orton in his latest report on Ohio. It is an extensive formation in eastern New York, having a thickness of 300 or 400 feet, but it becomes inconspicuous before reaching the western part of the State. In Indiana, also, it lies mainly outside the region here discussed. It is therefore of little importance to the present discussion.

Oriskany sandstone.—This formation, like the Lower Helderberg, is conspicuous in eastern New York, but thins out and disappears before reaching the western part of the State. Although its geographical distribution is about the same as the Lower Helderberg, its fauna and flora are very different, being pronouncedly Devonian.

The Sylvania sandstone of northwestern Ohio, which was at first referred to the Oriskany, was finally considered by Orton, on paleontological grounds, to be a part of the underlying formation, and therefore of Upper Silurian instead of Devonian age.

Corniferous limestone.—The rocks of the Corniferous epoch in New York include the Schoharie and Caudagalli grits as well as the Corniferous limestone; but only the limestone appears in western New York. It outcrops in a narrow strip leading eastward from Buffalo to the Hudson River. This limestone, being a more resistant rock in western New York than the formations immediately above and below, now presents a well-defined escarpment, over which several small streams have waterfalls. Hall divided it between the Onondaga and Corniferous, the former including the gray lower member and the latter the darker-colored upper member of the formation;[1] but the earlier classification by Eaton has now become established. The thickness of this formation in New York is commonly only 100 to 150 feet, but in the eastern part of the State it in places reaches about 250 feet.

[1] New York Geol. Survey, Fourth Geol. District, 1843, pp. 151–176.

In Ohio a Devonian limestone occurs, which is thought by Orton probably to cover more than the single epoch known as the Corniferous in New York. It forms the surface rock in a narrow strip, 5 to 15 miles in width, extending from Sandusky southward past Columbus into northwestern Pickaway County, lying immediately east of the outcrop of the Waterlime. It appears in a strip of similar width in northwestern Ohio, on the northwest border of the Waterlime. It also appears on some of the islands in the western end of Lake Erie, and on the elevated tract in Logan and parts of neighboring counties in west-central Ohio. Its thickness seldom exceeds 75 feet.

In Indiana the Corniferous or Upper Helderberg outcrops at intervals in a narrow belt extending northward from the Ohio River at the Louisville Rapids to Logansport. It is shown by well drillings to immediately underlie the drift in several counties north of the Wabash River in a belt extending from the Ohio-Indiana line westward about to Rensselaer. It is found to present considerable variation in color, composition, and texture in different localities. It is thought by Phinney to range from 30 to 65 feet in thickness, but as the data are largely from drillings this estimate of range may be only an approximation.

Marcellus shale and Hamilton formation.—The Marcellus shale of New York occupies a narrow depression along the southern border of the Corniferous limestone, from the vicinity of Cayuga Lake westward to the city of Buffalo. It is exposed only in a few valleys, the drift being so heavy as to conceal it elsewhere. The greatest observed thickness in western New York does not exceed 50 feet. A portion of it is very bituminous and of black color. This formation is considered by Hall to be a part of the Hamilton group, there being no well-marked line of separation from that group.[1]

The Hamilton group of New York consists of a series of shales with occasional thin beds of limestone, and attains a thickness in central New York of nearly 1,000 feet. Each member of the series thins gradually to the west, until at the border of Lake Erie the thickness of the entire group is scarcely 500 feet. The shales are of blue-gray or green color, and thus contrast strikingly with the dark Marcellus shale. The outcrop is confined to a narrow strip, scarcely 10 miles in average width, which extends from the

[1] New York Geol. Survey, Fourth Geol. District, 1843, p. 177.

eastern end of Lake Erie eastward past the northern ends of the Finger Lakes to the Hudson River Valley. This group of rocks forms the foothills of the elevated uplands which occupy the southern portion of western New York.

In Ohio there is only a thin development of this group of rocks in the central and northern parts of the State. This group may have a thin development in northern Indiana.[1] It is thought to be represented in the hydraulic limestone at the Louisville Rapids, on the south border of the State.[2]

Genesee, Portage, and Chemung, or Ohio shale series.—Under the names Genesee, Portage, and Chemung there are included in New York a complex series of shales with occasional beds of flagstone and sandstone. This series in Ohio appears to be represented by a single great shale formation, now known as the Ohio shale, but designated by the geologists of the first Ohio survey the "shale stratum" or "black slate." The apparently equivalent formation in Indiana is commonly called the "black shale."

The Genesee shale of western New York bears a striking resemblance to the Marcellus shale in color and general characteristics, but differs from it in fossils as well as in stratigraphical position. It is a thin formation, having a thickness of only 25 feet on the borders of Lake Erie and about 150 feet on the shores of Seneca Lake. It appears in the gorge of the Genesee at Mount Morris.

The Portage of western New York "presents an extensive development of shale, shales and flagstones, and finally some thick-bedded sandstone toward its upper part." It has excellent exposures in the gorge of the Genesee at Portage Falls. Hall has called attention to the influence of the sandstone in preserving the high ridges between the deep valleys of western New York, and also to their influence in producing cascades.[3]

The entire thickness of the Portage group on the Genesee is estimated by Hall to be fully 1,000 feet. At the New York-Pennsylvania line it is thought by White to rise 475 feet above Lake Erie, but near the Pennsylvania-Ohio line it passes below lake level.[4] Its outcrops in Erie County, Pa., are described by White as containing a succession of alternate

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[1] See Phinney: Eleventh Ann. Rept. U. S. Geol. Survey, Pt. I, 1891, p. 636.
[2] W. W. Borden: Fifth Ann. Rept. Geol. Survey Indiana, 1873, pp. 150, 161, 172.
[3] New York Geol. Survey, Fourth Geol. District, p. 225.
[4] Second Geol. Survey Pennsylvania, Rept. Q^4, 1881, p. 119.

layers of gray shale and thin layers of hard sandstone. Above the Portage in Erie County, Pa., is a shale formation about 225 feet in thickness to which White has given the name Girard shale, from Girard, Pa. It immediately underlies the typical Chemung formation and is regarded as a transition from the Portage to the Chemung.

The Chemung group of western New York is described by Hall as consisting of a "series of thin-bedded sandstones or flagstones with intervening shales, and frequently beds of impure limestone resulting from the aggregation of organic remains." Occasionally a coarse conglomerate appears as in the "rock cities" near Salamanca and Panama, N. Y. The name of the group is taken from the Chemung River, along which this group of rocks is finely displayed. The southern tier of counties in western New York is largely occupied by this formation, and it outcrops for a short distance southward in northern Pennsylvania. It forms the highest elevations in the eastern part of that region, attaining a height of about 2,500 feet above tide and 600 to 1,000 feet above the larger valleys which traverse it. At the western limits of the State the altitude of its surface has decreased to about 1,800 feet. The thickness of this group in the vicinity of the Chemung River was estimated by Hall to be not less than 1,500 feet, but it apparently decreases westward. There is some difference of opinion concerning the limits of the Chemung in northwestern Pennsylvania, it being uncertain whether it should include the Venango oil sands.

The area of outcrop of the undoubted Chemung in northwestern Pennsylvania is restricted to a narrow belt lying a few miles south of Lake Erie in Erie and northwestern Crawford counties and in the larger valleys of Warren and McKean counties. The Venango sands also have outcrops on ridges in the midst of the Chemung area and in a narrow strip on its south border. At the Pennsylvania-Ohio line the Chemung outcrop extends less than 20 miles south from the shore of Lake Erie. This formation constitutes the main part of the escarpment south of Lake Erie in northwestern Pennsylvania and northeastern Ohio.

The shales of northeastern Ohio as mapped by Read[1] include the Venango sands of the Pennsylvania survey, as well as the undoubted Chemung and the transition beds between the Chemung and Portage

[1] Geology of Ohio, Vol. I, 1873, p. 483.

formations. The entire group here consists almost wholly of shale, there being few layers of hard rock so much as a foot in thickness. Because of this absence of hard rock the slopes are worn down to regularity and do not present the benches or abrupt changes characteristic of the eastward extension of the upper members of the group.

The area of outcrop extends southward well toward the head of Grand River Basin in northern Trumbull County, but returns on the west side of that basin to within 10 miles of Lake Erie. It extends up Chagrin Valley to about Chagrin Falls, 20 miles from the Lake, and up the Cuyahoga Valley about 25 miles, or nearly to Peninsula. Aside from these extensions its outcrop from the Grand River Basin westward to the Huron River is but 5 to 15 miles wide, with an average of perhaps 10 miles. It extends northward beneath Lake Erie to an undetermined distance. The basin in which Lake Erie lies no doubt owes its existence chiefly to the soft and friable character of the rocks of this group. The thickness of the group near the south border of its outcrop south of Lake Erie is found to be about 950 feet at Elyria and 1,300 feet at Cleveland.[1] It apparently becomes much thicker in passing eastward from Cleveland into Pennsylvania and New York.

From near the mouth of Huron River, in Erie County, the belt of outcrop of this group turns abruptly southward, passing west of Norwalk, Galion, and Mount Gilead, and east of Delaware and Columbus. Below Columbus it occupies the Scioto Valley to the vicinity of Chillicothe and also for a few miles below Waverly. It appears also in valleys or narrow strips of lowland to the west of the Scioto, to and beyond the Ohio Valley. Its thickness, as reported by Orton, decreases from about 900 feet on the borders of Lake Erie to 450 feet in Crawford County, to 350 feet in Ross County, and to about 250 feet in Highland County.

Throughout the entire line of outcrop from the Ohio River northward to Lake Erie, as well as eastward into Pennsylvania, this group consists almost entirely of soft shales. These have not resisted erosion as well as the overlying beds, and hence are found mainly in basins or at the base of hills. In this respect they are in contrast with the New York portion of the outcrop, which, as above noted, occupies some of the highest ridges and hills of the western part of that State.

[1] See Orton: Geology of Ohio, Vol. VII, p. 24.

These shales also immediately underlie the glacial deposits in the northwestern part of Ohio and neighboring portions of Michigan and Indiana. They are, however, covered to a depth of 100 to 500 feet, as the drift in that region is exceptionally thick. The rock surface is consequently very low, a considerable part of it being below the level of Lake Erie. The thickness of the shales is not so great as in the eastern district, being but 100 to 150 feet in much of northern Indiana.

Another line of outcrop of these shales in Indiana is found in a narrow strip leading from the Ohio River at New Albany, in a course west of north, across the State, crossing the White River below Indianapolis and the Wabash River above Lafayette. Near Monticello it swings westward and enters Illinois west of Kentland, Ind. Along this line also its surface has a low altitude, but it is covered throughout much of its length by heavy deposits of drift. The southern end is nearly free from drift and presents the appearance of a broad valley. The thickness of this belt of shale, like that of the one farther north, is only 100 to 150 feet, or even less.

Waverly or Bedford shale.—This is the lowest formation in the complex series to which the geologists of the first Ohio survey gave the name Waverly, a series which, in Ohio, embraces the entire interval between the Ohio shales and the Conglomerate Coal Measures. This series of rocks has given rise to much discussion, but seems now to be more closely allied to the Eocarboniferous than to the Devonian formations.[1] The series between the Ohio shale and Conglomerate Coal Measures, as developed in Ohio, contains the following formations, given in order from older to newer: (1) Waverly or Bedford shale; (2) Berea grit and shale; (3) Cuyahoga shale; (4) Logan conglomerate; (5) Maxville limestone. In Indiana it is commonly known as the "Subcarboniferous," while in western Pennsylvania it was classed by I. C. White as the Subconglomerate series. It probably comprises much of the Catskill and Pocono formations of eastern Pennsylvania. White thinks it probable that the red Bedford shale and the Berea grit are of Catskill age.

The Waverly shale includes not only the formation in southern Ohio, thus described by the Ohio survey, but also the Bedford shale of northern Ohio as defined by Newberry, with its included Euclid and Independence building stone.

[1] For a summary of the questions in dispute see Herrick: Geology of Ohio, Vol. VII, 1894, pp. 495–515.

A shale which is, perhaps, the equivalent of the Waverly is present in northern Indiana in greater thickness than in Ohio, the thickness as reported by Phinney being 143 feet at South Bend, 215 feet at Elkhart, and 200 feet at Goshen.[1] The formation occupying the base of the Waverly series in southern Indiana is the Rockford (Goniatite) limestone. It may not, however, be the precise equivalent of the Waverly shale.

Eastward from northern Ohio the Waverly shale changes from a blue-gray to a red color. It is thought by Carll to be developed only in a narrow belt in northeastern Ohio and northwestern Pennsylvania, and that mainly under cover of later rock formations.[2]

Berea grit and shale (Catskill?).—The Berea grit, although but a few feet in thickness, is one of the most persistent and easily recognized formations in eastern Ohio and northwestern Pennsylvania. Concerning it Orton has remarked: "Its persistence as a stratum is phenomenal. Seldom reaching a thickness of 50 feet, its proved area in Ohio, above ground and below, is scarcely less than 15,000 square miles, and beyond the boundaries of Ohio it appears to extend with certainty and strength unbroken into at least four adjacent States."[3] The name is taken from Berea, in northern Ohio, where it is extensively quarried. It constitutes the "Waverly quarry stone" of southern Ohio. It has had considerable influence in producing cascades in northern Ohio. In both the exposed and the covered portion it consists of a sandstone of medium coarseness, which in northern Ohio includes a thin pebble bed.

Above the Berea grit is a dark shale 15 to 20 feet in thickness, which has been reported by Orton to form a constant cover throughout its entire extent in Ohio. It is usually sharply in contrast with the blue beds of the overlying Cuyahoga shale, but from Cuyahoga County eastward the line of separation is in places not easily traced.

Cuyahoga shale (part of Pocono sandstone of Pennsylvania).—This formation, which in Ohio has a thickness of 150 to 400 feet, receives the name Cuyahoga from extensive outcrops along the Cuyahoga River. It constitutes the main member of the Waverly series, though the Logan conglomerate of central and southern Ohio rivals it in strength. It consists, in the main, of light-

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[1] Eleventh Ann. Rept. U. S. Geol. Survey, Pt. I, 1891, p. 638.

[2] Second Geol. Survey Pennsylvania, Rept. I^3, 1880, map, p. 92; discussion, pp. 96–97.

[3] Geology of Ohio, Vol. VII, p. 28.

colored, blue or gray shales, but carries occasional thin beds of sandstone. In southern Ohio, notably in Ross, Pike, and Scioto counties, the sandstone beds become more prominent. The sandstone is extensively quarried at Buena Vista, on the Ohio River, a few miles below Portsmouth. There are also developments of sandstone in northeastern Ohio, notably in Trumbull County, where numerous quarries have been opened. Its outcrop usually covers a width of several miles.

From the Ohio River northward to Chillicothe the Cuyahoga shale outcrops on both sides of the Scioto River, but north of that city it lies east of the river and forms the east border of the Scioto Basin. It outcrops in a narrow strip south of Lake Erie from Lorain County eastward to Geauga County, but there swings southward around the head of Grand River Basin.

In northwestern Pennsylvania this formation, under the name of Pocono sandstone and Crawford shales, covers the uplands in a belt 10 to 15 miles wide in Crawford and southeastern Erie counties and extends southeastward along the lowlands into Mercer and Venango counties. It forms much of the surface in the northern half of Warren County and extends southward along valleys and low parts of the upland beyond the limits of that county. It outcrops only on a few ridges in southwestern New York.

This formation apparently constitutes the lower part of the Knobstone group of Indiana, so well developed on the west border of the Cincinnati arch. It there forms the slopes of the prominent escarpment west of the trough occupied by the Devonian shale, but it lies mainly outside the limits of the region under discussion.

Logan conglomerate (part of Pocono sandstone of Pennsylvania).—The Logan conglomerate is well developed from Wayne County, Ohio, southward into Kentucky, but seems to be feebly developed or wanting in the vicinity of the Cuyahoga Valley. It is characterized at two horizons by a conglomerate which carries small pebbles. The conglomerate phase is not so conspicuous in southern as in central Ohio, and in the latter district occupies only a small part of the formation, there being fine-grained sandstones and even shales embedded with the conglomerate. The average thickness of the Logan conglomerate group is about 200 feet, but the maximum is much above the average, reaching probably 400 feet. The resistance of this conglomerate

to erosion has produced a marked effect upon the contours of the valleys, causing, in some instances, notable constrictions, as shown below.

This formation constitutes part of the Knobstone of Indiana. The name Knobstone, there as well as in Kentucky, arises from the topographic features resulting from its persistence as a protective capping on the summits of the ridges and hills. The knobs of southern Indiana rise abruptly 300 feet or more above the shale lowland to the east.

Above the Logan conglomerate there is a local development of limestone in south-central Ohio, which was classified by Prof. E. B. Andrews, from a study of fossils, as an equivalent of the Chester limestone of Illinois and Missouri, or the latest of the Eocarboniferous series. It is known as the Maxville limestone, from a locality in Perry County, and is probably best displayed on Jonathan Creek in Muskingum County. It has a thickness of only a few feet and the outcrops are mainly on valley slopes.

Pottsville, or Conglomerate Coal Measures.—The series of formations in which the coal seams are embraced are found in a large basin extending from northern Pennsylvania and northeastern Ohio southward to eastern Tennessee. The Ohio River traverses the northern half from Pittsburg, Pa., to Marietta, Ohio, below which it bears toward the western margin of the basin and leaves it a short distance above Portsmouth, Ohio. The area covered by these formations in Ohio is estimated by Orton to be about 10,000 square miles, or about one-fourth the area of the State. Pennsylvania and West Virginia each have an area about as extensive as that of Ohio. A few square miles in southwestern New York, chiefly in the portion of Cattaraugus County south of the Allegheny River, fall within the limits of this basin. By reason of being in a basin which was in process of filling, the lowest members appear on the borders, while the highest are found in its interior portion.

At the base of these formations there is found a series of conglomerates and sandstones with thin beds of shale and limestone, and with local developments of coal, to which the general name Conglomerate group has been applied. In the Pennsylvania reports it has the names Seral conglomerate and Pottsville conglomerate, and constitutes No. XII of the rock series of that State.

Allegheny, or Lower Productive Coal Measures.—Next above the series of conglomerates and sandstones just discussed come the Lower Productive Coal Measures, which have a thickness about as great as the entire Conglomerate group.

They carry not fewer than nine workable coal seams in Pennsylvania and six well-defined seams in Ohio These are thrown into three groups, known as the Clarion, the Kittanning, and the Freeport, each of which in Pennsylvania carries three coal seams. The outcrops are around the borders of the coal basin, but the formation probably underlies the interior portion.

Conemaugh, or Lower Barren Coal Measures.—Above the Lower Productive Coal Measures there are 300 to 600 feet of sandstones and shales in which the few coal seams that appear are thin and wanting in persistency. For this reason, and because of a similar series at a higher horizon, they are known as the Lower Barren Measures. One coal seam, the Mahoning, is worked in Columbiana County, Ohio. These barren measures outcrop extensively in southeastern Ohio at a distance of 30 to 50 miles back from the Ohio River, but come to the border of the Ohio Valley in eastern Ohio and western Pennsylvania.

Monongahela, or Upper Productive Coal Measures.—The Lower Barren Measures are overlain by the Upper Productive Coal Measures, which carry the widely known Pittsburg coal (the most valuable seam of this great field), and a less important seam, known as the Meigs Creek coal. The thickness of these measures has been estimated by Orton to be 250 to 300 feet, though the upper limits are not well defined. The extent is much greater than the limits of the productive portion of the Pittsburg coal.

Dunkard beds (Permian?).—Above the Upper Productive Measures there is a formation which attains, where best developed, a thickness of several hundred feet, and which has long been known as the Upper Barren Coal Measures. But since the fossil plants of this formation are of Permian rather than Coal Measures type, the formation can scarcely be retained as a part of the Coal Measures. The name Dunkard, taken from a creek in southwestern Pennsylvania, where the beds are well developed, has been substituted for the former name. This formation, as interpreted by Orton, covers only a small area in Ohio, being confined chiefly to Belmont and Monroe counties, but it occupies a large area in West Virginia between the Ohio and Monongahela rivers, and encroaches slightly on southwestern Pennsylvania.

This is apparently the newest rock formation in the region under discussion. Only the residuary clays and a few beds of gravel at high levels are present to bear witness to the several long periods that intervened between Carboniferous and Glacial times.

CHAPTER II.

PHYSICAL FEATURES.

ALTITUDE.

If the basin of Lake Ontario be included, the altitude of the glaciated portion of this region has a range of about 3,000 feet, the lowest part of the Lake Ontario Basin being nearly 500 feet below sea level, while the highest ridges on the Allegheny Plateau are fully 2,500 feet above the sea. This range is found within a distance of about 100 miles. The shore of Lake Ontario stands about 250 feet above tide, the level of the lake ranging from 244.5 to 249 feet, thus reducing the variations of the exposed land surface to about 2,250 feet. The areas embraced between 500-foot contours are approximately shown on Pl. I.

This region attains its highest altitude in the vicinity of the headwaters of the Allegheny and Genesee rivers, in Potter and McKean counties, Pa., and Allegany and Cattaraugus counties, N. Y. These counties include nearly all the area that rises above 2,000 feet, though there are a few square miles in the adjacent portions of Warren County, Pa., and Chautauqua and Wyoming counties, N. Y., which rise above that elevation. It will also be observed that the portion of this region rising above 1,500 feet is confined almost wholly to the States of New York and Pennsylvania, there being scarcely 1 square mile of Ohio that is known to rise above this height, while the highest points of Indiana are only about 1,250 feet. The 1,000-foot contour embraces all of western New York and northwestern Pennsylvania except the lowlands that border Lakes Ontario and Erie and a few of the deep valleys. This contour also embraces much of the eastern half of the State of Ohio; also large areas in the western half. The main areas standing below 1,000 feet are the Grand River, Scioto, and Maumee basins and a large part of the watershed of the Great Miami River. In Indiana a small area in the northeastern part and a larger area in the eastern part rise above 1,000 feet. With these exceptions only a few isolated ridges and hills, chiefly in the southern part of the State, rise above that contour. The

greater part of Indiana and large areas in Ohio fall between 500 and 1,000 feet. The only portions of the region falling below 500 feet are a narrow strip in New York, on the south border of Lake Ontario, and a portion of the valley of Ohio River and the lower courses of its tributaries in southern Ohio and Indiana. Near New Albany, Ind., the 500-foot contour recedes a few miles from the Ohio River into the lowland formed in the Devonian shale, but returns to the river just below that city.

TOPOGRAPHY.

In the description of the rock formations it was shown that all the earlier formations from the Trenton group up to the Hamilton contain a large amount of limestone and easily disintegrated shale, while the later formations contain very little limestone, and often are made up largely of resistant sandstone. This difference in constitution and texture has resulted in a marked difference in topography. The formations which contain a large amount of limestone or soft shale have become broken down to a markedly lower elevation and a more even surface than the resistant sandstone.

The sandstone or hilly country, being mainly on the borders of the Appalachian Mountain system, occupies the southeastern part of the region under discussion. The border between it and the lower plain underlain by shale and limestone may be roughly indicated as follows: From the Genesee Valley at Mount Morris it takes a westward course, passing a few miles south of Batavia and Buffalo, N. Y., to Lake Erie. It follows the lake border southwestward to the vicinity of Cleveland, Ohio, lying usually but 5 to 10 miles south of the lake, though at the Grand River Basin in northwestern Ohio it extends southward about 40 miles. A short distance west from Cleveland the hills bear away from Lake Erie to the vicinity of the continental divide in Medina, Ashland, and Richland counties. From near Mansfield in Richland County the border turns southward and maintains this course for nearly 100 miles, constituting the eastern rim of the Scioto Basin. It then swings westward across northern Ross County, passing a short distance north of the city of Chillicothe, and enters the northern part of Highland County. Here it again turns southward and passes through Highland and Adams counties into Kentucky, crossing the Ohio River near the mouth of Brush Creek, a few miles above Manchester, Ohio.

On the borders of the Ohio the plain is so dissected as to appear less

strikingly in contrast with the hills than in districts farther north, yet the regular crest lines of the dividing ridges are a rather striking feature even there. The plain extends westward across the Cincinnati arch into Kentucky, Ohio, and Indiana, to the Knobstone formation of southern Indiana and northern Kentucky. It covers northern Kentucky, northwestern Ohio, and the southern part of Michigan, and thence stretches westward far beyond the Mississippi River, constituting the great interior plain of the United States.

In both the plain and the hilly country there are variations in topography which need to be considered in some detail. The hard and resistant rocks of the plain country stand in relief as escarpments or, in some cases, as low dividing ridges, while those of the hilly country remain as elevated divides between drainage lines or occasionally as island-like outliers. The glacial deposits have greatly concealed the topography of the rock formations and disturbed the old systems of drainage. In the plain portion of the region the old valleys have been so greatly filled that they can be traced only in limited districts. In the hilly portion the drift seldom fills up the lowlands to the height of the uplands or ridges, yet it obscures the old drainage lines to a great degree.

The present discussion is naturally devoted chiefly to the eastern part of the region, where the old topography is least concealed. Inasmuch as the topographic features depend largely upon the rock formations, they are to some extent discussed in belts that follow the outcrops of the formations. The plain south of Lake Ontario in western New York is first discussed, and then the region lying southward and westward, comprising the later formations, is described.

LOW PLAIN SOUTH OF LAKE ONTARIO.

The low country south of Lake Ontario in western New York is separable into three distinct plains, with two escarpments above the level of the lake shore. These features are in part represented on Pl. III. The first or lowest plain extends from the lake southward to the Niagara escarpment, a distance of 6 to 12 miles; the middle plain extends from the Niagara to the Corniferous escarpment, a distance of 10 to 15 miles; while the highest plain extends from the Corniferous escarpment southward to the base of the hilly country, with a width averaging less than 10 miles. These plains are underlain by shale formations, except for a short distance

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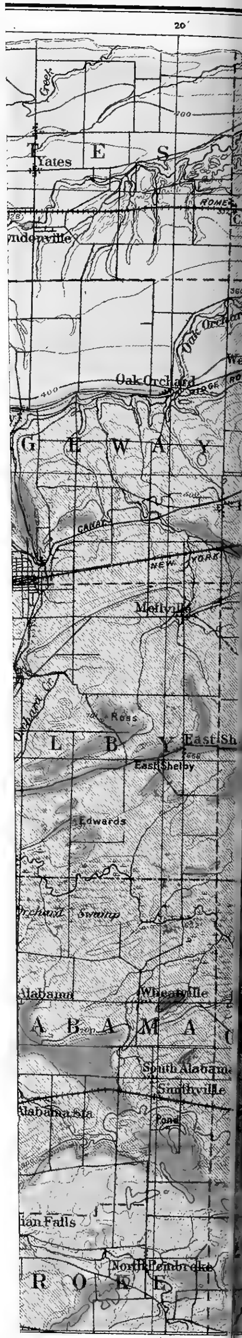

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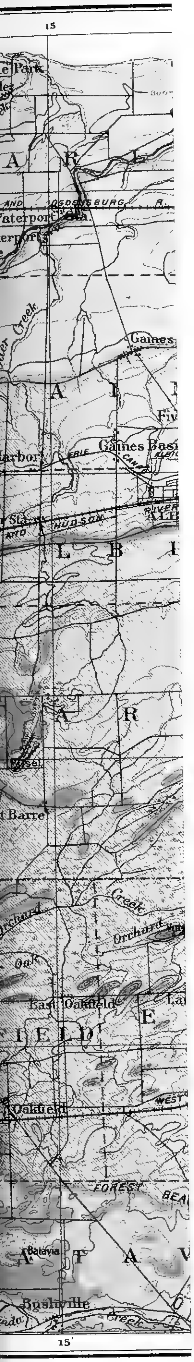

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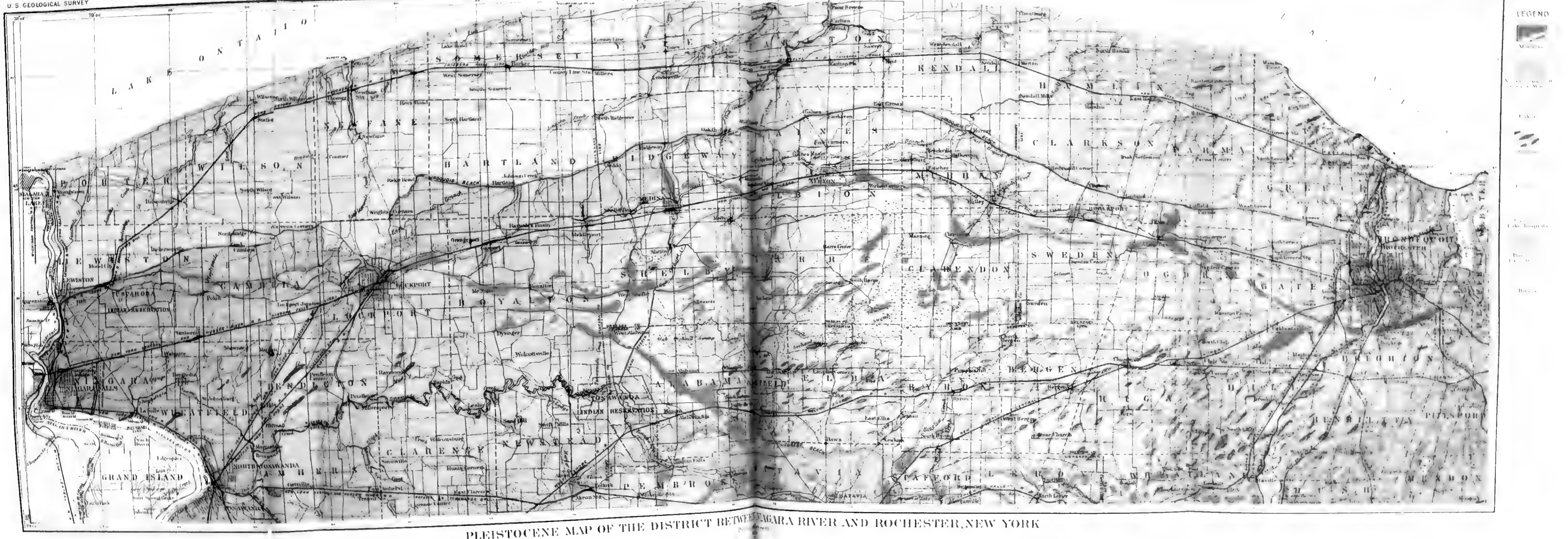

PLEISTOCENE MAP OF THE DISTRICT BETWEEN NIAGARA RIVER AND ROCHESTER, NEW YORK

south from the brow of the escarpments, where in each case limestone forms the surface rock.

The surface rock of the lowest plain is the soft shale of the Medina group, and this formation extends northward beneath the lake. There is a rise of 100 to 175 feet in passing southward across it from the lake shore to the base of the escarpment. The plain is generally so smooth that its slopes are barely detectible by the eye, but instrumental determinations show that it has troughs and ridges of sufficient variation in altitude to control the drainage. This plain and the escarpment bordering it were made a subject of special study by Gilbert in 1898, and some results of the study, presented to the Geological Society of America, have recently appeared.[1] Gilbert found that the courses of drainage are controlled by shallow troughs which have a trend from northeast to southwest, in harmony with the general direction of ice movement, as shown by striæ. The depth of the troughs is not definitely known, since they are usually drift filled to such a degree that surface wells do not penetrate the filling. It is found, however, that some of the troughs exceeded 40 feet in depth. Gilbert considers it highly probable that this furrowing of the surface is the result of glacial erosion. He thinks that the erosion much exceeds the amount represented by these channels, for it appears to have obliterated the preglacial topography, which presumably included a system of shallow valleys descending northward with the general slope of the country. He estimates that the general reduction of the surface must have been at least 40 to 50 feet, and it may have been considerably greater. It is, however, his opinion that the Niagara escarpment antedated the period of glacial sculpture, though the ice erosion rendered it more prominent by excavation along its base and by the general degradation of the lowland it overlooks.

This plain was nearly covered by the glacial Lake Iroquois, the Iroquois beach being situated either along the base of the escarpment or within a mile or so north of it. The lake has removed to a perceptible degree the fine material from the higher portions of the plain and silted up the hollows with its sediment, thus producing an important subduing influence on the topography. That it has degraded the surface of the ridges is shown by the large amount of coarse pebbly material which remains as a residue on the higher or more exposed parts of the lake plain.

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[1] Glacial sculpture in western New York, by G. K. Gilbert: Bull. Geol. Soc. America, Vol. X, 1899, pp. 121–130.

NIAGARA ESCARPMENT.

This escarpment, which marks the northern limit of the Lockport limestone in western New York, has a height ranging from about 200 feet in the vicinity of the Niagara River to 50 feet or less in the vicinity of the Genesee River. As shown on the topographic map (Pl. III), it is prominent for 50 miles east from the Niagara River, its height seldom falling below 100 feet, but in the remaining 20 miles to the Genesee it is comparatively inconspicuous. The altitude above tide declines from about 640 feet in the western portion to scarcely more than 500 feet in the vicinity of the Genesee River.

At the brow of the escarpment the limestone is present only in small amount, and, as noted by Gilbert, is absent from the immediate edge of the cliff through considerable spaces. It thickens rapidly upon passing southward, though not sufficiently to overcome the dip of the strata. The southern boundary of the outcrop is 50 to 75 feet lower than the northern. Below the Lockport limestone there is about 80 feet of Rochester shale, 25 feet of Clinton limestone, and then a great body of Medina shale containing a few sandstone ledges near the top. The sandstones are discontinuous and lie at various depths below the Clinton limestone, the range as given by Gilbert being from 40 to 100 feet. In places the Medina and Clinton beds are worn back to the base of the Niagara escarpment, while in other places they extend out short distances to the north, forming a lower escarpment rudely parallel with the main escarpment.

Gilbert's studies lead him to think that these resistant ledges of the Clinton and Medina have been worn back so far by glacial erosion as to lose the contours typical of subaerial erosion. They do not present the sharply outlined salients and reentrants which characterize the brow of the escarpment. He found the brow of the escarpment to be more regular in outline where it stood nearly in line with the ice movement than it is where it faced against the ice movement. In the latter case its contours are deeply serrated or inflected, the axes of serration being parallel with the glacial striæ. On the serrated face furrows were formed, which range in depth from 10 to 30 feet and which have usually a breadth of several hundred feet. The longest of them probably extends more than half a mile back from the escarpment. These rock furrows are now largely filled with drift, yet are plainly discernible on the topographic sheets (see Pl. III). The

regularity of the contours in the portions trending northeast to southwest is here shown to be strikingly in contrast with the portions that trend northwest to southeast. The effect of glacial erosion on the brow of the escarpment appears therefore to have been insufficient to remove the salients and reentrants of the preglacial topography. It is estimated by Gilbert that the limestone at its escarpment lost on the average only 10 to 20 feet of thickness, while from the broad belt of outcrop the general loss may have been as small as 5 feet. The minor ridges of the limestone surface do not conform in trend to the direction of the ice motion, as do the ridges of the Medina shale, and the amount of erosion in the limestone is thought to be scarcely one-tenth as great as in the shale. The discriminating studies begun by Gilbert promise to throw much light upon the question of the share of work borne by ice in the production of the topographic features of the glaciated districts, including that of the origin of the basins of the great Laurentian lakes.

To this escarpment is due the great cataract of Niagara and the lower or Rochester Falls of the Genesee River, as well as several falls in small streams that pass over it. At the Genesee River and on Oak Orchard Creek cascades occur at the points where these streams cross the Medina sandstone and Clinton limestone as well as the Lockport limestone. The Niagara cataract has only the one fall, which extends from the top of the Lockport limestone down below the Clinton, with a submerged gorge extending down into the Medina shale. The writer has nothing to add to Hall's interpretation of the development of the three falls on the Genesee at Rochester.[1] The falls on the smaller streams may be passed with this simple mention of their occurrence, since the writer has made no special study of them.

PLAIN SOUTH OF NIAGARA ESCARPMENT.

Between the Niagara and Corniferous escarpments there is a plain 10 to 15 miles in width which, as indicated by the topographic map (Pl. III), descends for a few miles south from the Niagara escarpment and then rises gradually toward the base of the Corniferous escarpment. It thus forms a shallow trough affording a natural avenue for drainage along its axis. The western portion is utilized by the lower course of Tonawanda Creek, a tributary of the Niagara River; the middle portion by the upper course of

[1] New York Geol. Survey, Fourth Geol. District, 1843, pp. 381–382.

Oak Orchard Creek, a tributary of Lake Ontario; and the eastern portion by Black Creek, a tributary of the Genesee River. The portion north of the axis is chiefly underlain by the Lockport limestone, but the portion south is developed in the soft rocks of the Onondaga salt group. The amount of drift is so great that the preglacial valleys are completely concealed. Whether the Onondaga formation was sculptured by the ice sheet in a manner similar to the sculpturing in the Medina shale can not easily be determined on account of the great amount of drift. On hypothetical grounds the material removed by the ice sheet may be inferred to be of large amount, for the formation would be likely to offer but little more resistance to erosion than was offered by the Medina shale.

The western portion of the plain carries a few drumlins, while the eastern portion is characterized by numerous drift ridges, some of which are of drumlinoid and others of morainic type.

Although this plain was entirely covered by the waters of the glacial Lake Warren for a period sufficiently long to form a well-defined shore line, the waves have only removed or toned down the lesser irregularities of the drift surface and cut slight benches and built small bars and spits on the borders of the drift knolls.[1]

Upon the lowering of the lake level from the Warren to the Iroquois beach this plain appears to have been occupied by a shallow lake, which discharged across the Niagara escarpment at several points. Eventually the lake was drained and the discharge from the Lake Erie Basin found its way across this plain by two main channels, one of which crossed the Niagara escarpment along the line of the Niagara River, while the other took the course followed by the Erie Canal to Lockport, as pointed out by Gilbert.[2] The volume of water along the channel followed by the Erie Canal is thought by Gilbert to have been great and to have been maintained for a considerable time, for it produced a well-defined channel and carried a large amount of material over the escarpment to the lower plain. The Niagara route finally absorbed the entire drainage, and the falls are now receding through the plain between the Niagara and Corniferous escarpments.

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[1] See Fairchild: Bull. Geol. Soc. America, Vol. VIII, 1897, pp. 272–284.

[2] Old tracks of Erian drainage in western New York, by G. K. Gilbert: Bull. Geol. Soc. America, Vol. VIII, 1897, pp. 285–286; also Vol. X, 1899, p. 129.

CORNIFEROUS ESCARPMENT.

This escarpment follows the north border of the outcrop of the Corniferous limestone from the rapids at the head of the Niagara River eastward past Williamsville, Akron, Indian Falls, Batavia, Fort Hill, Mumford, and Garbuttsville, coming to the Genesee River a short distance above Scottsville. The elevation above the plain on the north seldom exceeds 100 feet, but the escarpment is nearly continuous. The only noteworthy break is at Batavia, where occurs a gap about 2 miles in width that was apparently the old passage for a stream which drained the valley now occupied by the head-water portion of Tonawanda Creek. The altitude of the escarpment is fully 900 feet above tide in the vicinity of Batavia, but it declines to about 600 feet at Buffalo, and to a level nearly as low at the Genesee River.

There are two notable falls on the line of this escarpment, one at Tonawanda Creek near the village of Indian Falls, the other on Oatka or Allens Creek near Fort Hill. Each of these falls has receded about a mile from the brow of the escarpment, leaving a narrow rock gorge about 100 feet in depth in the line of the recession. The smaller streams which cross the escarpment also present cascades. In some cases streams which cross the Corniferous limestone disappear in fissures and caves which open out into the lower plain north of the escarpment. In dry seasons the waters of Allens Creek disappear in this manner near Le Roy, as pointed out by Hall[1]

PLAIN SOUTH OF CORNIFEROUS ESCARPMENT.

The narrow plain or lowland tract which lies between the Corniferous escarpment and the hilly portion of western New York extends westward along the south border of Lake Erie far into Ohio, with the same width as in western New York, 5 to 10 miles. It opens at the west into the great plain of the interior portion of the United States; it also extends southward into Grand River Basin to a distance of nearly 40 miles from Lake Erie. The portion east of Buffalo is all that will be considered under the present heading. It is underlain by the shales of the Marcellus and Hamilton formations, while the plain along the south border of Lake Erie is underlain by later formations.

On this plain there is not a marked descent southward from the brow

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[1] New York Geol. Survey, Fourth Geol. District, 1843, p. 169.

of the Corniferous escarpment, such as characterizes the plain south of the Niagara escarpment. On the contrary, a somewhat rapid rise is found in passing from the Corniferous escarpment back to the base of the hills. Much of the border stands 900 to 1,000 feet above tide, or 100 to 300 feet or more above the brow of the Corniferous escarpment. Notwithstanding this rapid rise the surface of the lowland is markedly less hilly than that of the region to the south. The central portion for a few miles on either side of Batavia stands above the level of the glacial Lake Warren, but the eastern and western portions were largely covered by the waters of that lake. The portion not covered by Lake Warren is largely occupied by a complex morainic system, which gives it a sharply undulatory expression.

It is probable that the ice sheet removed much material from this lowland and obliterated the preglacial topography to a marked degree. The amount of drift, however, is so great that it is difficult to ascertain the topography of the underlying rock surface. The present rivers appear to be largely independent of preglacial lines in their passage across the lowland.

GRAND RIVER BASIN.

From near Buffalo, N. Y., westward to Cleveland, Ohio, there is a narrow plain or strip of lowland on the south border of Lake Erie, extending back usually 5 to 10 miles from the lake shore. But in northeastern Ohio an arm or extension of this plain, known as the Grand River Basin, reaches back to the vicinity of Niles, a distance of about 40 miles from the lake. It is only 8 to 12 miles in width, and stands 150 to 300 feet above Lake Erie. If, however, the drift were removed, much of it would be level with the lake. As indicated below, this basin appears to have been the old line of discharge for a large part of the upper Ohio watershed. It is now occupied throughout much of its length by the headwater portion of Grand River, a small tributary of Lake Erie. Its southern end is crossed by the Mahoning River, which belongs to the present drainage system of the Ohio. This basin is excavated in the upper portion of the Ohio shales (the equivalent of much of the Chemung formation) and in the Waverly, Berea, and Cuyahoga shales and sandstones. The remainder of the plain bordering Lake Erie between Buffalo and Cleveland is chiefly in the Portage and Chemung formations, which are the equivalent of the lower portion of the Ohio shales. The softness of these formations along the border of Lake

Erie, compared with their texture in the districts farther east, accounts in large part for the low altitude to which they have been reduced. It is in this basin that the Grand River glacial lobe, discussed below, was developed.

SCIOTO RIVER BASIN.

From the western part of Lake Erie a low belt extends southward through the drainage basin of Sandusky River and thence across the continental divide into the region drained by the Scioto River, as may be seen by reference to Pl. I. Its southern limits are near the city of Chillicothe, where, as indicated above, the hilly country extends across to the west side of the Scioto. Southward from the continental divide this lowland has the form of a basin with well-defined rims on both the east and the west, but from this divide northward, while the eastern rim continues prominent, the western rim gradually disappears. The basin proper, therefore, lies mainly within the Scioto watershed and is commonly known as the Scioto Basin. It is about 75 miles in length and 40 miles or more in width.

There is a rise of about 300 feet in passing from the shore of Lake Erie southward to the continental divide near Marion. This rise is not uniform, there being directly south of Sandusky an ascent of about 200 feet within 10 to 12 miles, while not far away on either side nearly twice that distance must be covered to attain as great an altitude. From this continental divide the altitude decreases gradually along the axis of the Scioto Basin nearly to its southern end, but as it amounts to only about 200 feet in 50 to 60 miles the descent is not perceptible to the eye. From the Scioto River there is a rise of about 300 feet to both the east and the west within a distance of 20 to 25 miles, yet this rise is scarcely perceptible.

The eastern rim of the basin is found at the west border of the hilly country, where the resistant rock formations set in. It is made somewhat regular by the drift filling, which conceals gaps between hills. The western rim is made up in part of an old rock divide and in part of morainic accumulations. Rock is struck at shallow depths on portions of either rim, while in other portions it is covered to a depth of 250 feet, or even more. The eastern rim is crossed by buried preglacial valleys leading through to the Scioto Basin. It is not entirely certain that such valleys lead across the western rim. Natural exposures and borings indicate that the rim can have at most only narrow breaks, and it is possible that a practically con-

tinuous preglacial divide follows it underneath the present divide. There is certainly a much greater general altitude of rock surface along that rim than along the axis of the basin, and a somewhat higher altitude than in districts to the west.

The Scioto Basin appears to have been formed largely in the Devonian shale, though the shales now cover only a small part of it, so extensive has been their removal. The western rim of the basin owes its relief chiefly to the resistance offered by the limestone which underlies it; but the morainic ridges which follow it aid perceptibly in rendering it conspicuous. This basin was occupied by the most prominent glacial lobe of the three which were developed in Ohio, the Scioto. Its influence in causing lobation is considered in the discussion of that lobe.

MAUMEE RIVER BASIN.

From the western end of Lake Erie a low plain about 50 miles in width extends southwestward across northwestern Ohio and northern Indiana, the altitude of whose rock surface is about as low as the surface of the lake. The plain also extends along the south border of Lake Erie into connection with the lowland tract along the Sandusky River above described. Toward the south there is a gradual rise in the rock surface as far as the continental divide in northwestern Ohio, and a similar rise is found in passing northward into Michigan. In northern Indiana the basin apparently extends about to the Wabash River, the altitude of the rock surface being markedly higher in the district south of the river than in that on the north. Its northern limits are at a line passing westward through southern Michigan.

This basin, like the Scioto, was formed largely in the Devonian shale, while the higher land on its borders is underlain by more resistant strata, that on the south being limestone, while that on the north is largely sandstone. At its eastern end it received the Erie or Maumee lobe, and the western portion was occupied by the Saginaw lobe, which extended into it from the northeast. The interlobate moraine built up between these lobes rises in places over 600 feet above the level of the rock floor of the basin. The drift filling probably averages 200 feet throughout the basin.

UPLAND PLAIN OF WESTERN OHIO AND EASTERN INDIANA.

The preglacial topography of the remainder of the region west of the hilly country of Ohio is so greatly disguised by drift that it must be largely conjectured from well data. The drift usually overtops the old divides, making it difficult to trace their position. From the available data it appears that much of western Ohio and eastern Indiana had a somewhat uniform upland level between 800 and 1,000 feet above tide, or nearly 300 feet above the lower portions of the Maumee and Scioto basins. The rim on the western border of the Scioto Basin has a rock surface standing in places 1,200 to 1,300 feet above tide, but averaging scarcely more than 1,100 feet. There was also an altitude of about 1,100 feet in the high part of Indiana near the headwaters of White and Whitewater rivers, in Randolph and Wayne counties. It was at these high parts of the upland that reentrants were formed between the ice lobes, as shown by the morainic loops.

KNOBSTONE ESCARPMENT AND SHALE BASIN OF SOUTHERN INDIANA.

At the western border of the region under discussion in southern Indiana there is a prominent escarpment of the Waverly or Knobstone, facing a low basin formed in the Devonian shales. Its highest points, however, are but little more than 1,000 feet above tide, and its general elevation is about 900 feet. Its prominence is due, therefore, not to great altitude, but to the contrast with the low-lying basin on its border. This basin stands scarcely more than 500 feet above tide and is so narrow as to resemble a broad river valley. It was apparently formed, however, by subaerial degradation rather than by active stream corrasion. That it was not formed by glacial action is shown by its having in the unglaciated districts about the same depth and breadth as in the glaciated

HILLY COUNTRY.

The topography of the hilly portion of the region under discussion appears to be as largely due to the action of streams and ordinary subaerial degradation as that of the plain portion. The folds, faults, or other disturbances of the strata have been in neither case sufficient to produce an appreciable effect. The writer has been unable to discern remnants of a peneplain in any part of this hilly country. The highest hills probably stand somewhat below the old Cretaceous peneplain so well displayed on

the border of the southern portion of the Appalachian Mountain system. The slowness of the breaking down of the hilly country, compared with that of the bordering plain country, as above noted, seems due to the more resistant nature of its rocks. Had its strata been as soluble and friable as those of the plain country its surface would probably have been reduced to a level correspondingly low. Had there been greater uniformity in texture these formations, like the limestone formations, might present a near approach to a plain. But their variability has caused an uneven degradation which has resulted in the development of a hilly country. The uplands, the slopes, and the valley bottoms have each developed types of topography consistent with the varying resistance of the rock strata which underlie or border them.

The amount of drift is so great on the border of this hilly country as to obscure to a considerable extent the topography of the rock surface. But toward the glacial boundary the concealment becomes less, and opportunity is afforded for comparing the rock contours of the glaciated with those of the unglaciated tracts. This comparison has shown the modification by glacial erosion to be surprisingly small in the vicinity of the glacial boundary. It will be very difficult to determine the extent of glaciation by a study of topographic maps. Take, for example, the Olean quadrangle, New York (Pl. IV), which embraces both glaciated and unglaciated tracts. The changes produced by glacial erosion are so few and so slight that neither a map nor a study on the ground makes the extent of glaciation clear. It is determined only by a careful search for glacial deposits.

The hills occasionally present abrupt slopes, or even mural faces, where the hard ledges outcrop, but usually they rise with gentle grade and give generally the impression of a moderately rolling country. A considerable part of the region may be easily brought under cultivation, and it is already largely an agricultural district.

The breadth of the dividing ridges is subject to much variation on account of differences in resistance of the rock strata. If hard strata lie near the surface a broader divide may be expected than where the rocks are soft. It is not necessary, however, that the uppermost rock should be hard. Often a hard ledge extending from the brow of the bluff back beneath the divide serves as a table to support softer strata which cover it. Similarly,

the hills and knobs may have soft beds at the top which are supported by hard ones that outcrop along the side. Near the north end of the hilly country in western New York the hard sandstones of the Portage group have withstood denuding action to a remarkable degree, as shown in the following description by Hall:[1]

> These often extend northward on the elevated grounds between the deep north-and-south valleys, presenting a gentle northern slope to the shales of the Hamilton group, while on the sides of the same hills the slope is abrupt, and the surface being but little covered with northern drift, the valleys are bounded on either side by steep hills.
>
> This character is well illustrated along the southern part of the Genesee Valley toward Dansville, and in the valleys of Allen Creek, the Tonawanda, and the different branches of the Seneca and Cayuga creeks. The valleys just spoken of, in their course through the Hamilton group, present gently sloping sides, and the country rarely rises above the level of the valley bottom or bed of the stream. On approaching the northern margin of the Portage group the observer finds gradually increasing elevation of the hills on either side and an abruptness of their slope, and in a short time he finds himself in a deep valley, bounded on either side by hills rising 400 or 500 feet, and in some instances even 800 feet above the level of the stream.

The upland surface presents numerous low passes which cross the divides and have cols or saddles in some cases standing several hundred feet below the highest points on the bordering uplands. The low altitude of the passes strongly supports the interpretation that the hilly region would have been reduced to a level in harmony with that of the bordering plain country if the strata had been correspondingly weak. Several of these passes are represented on the map of the Olean quadrangle (Pl. IV). They may be seen in all parts of the hilly country both outside and inside the glacial boundary. They are therefore not dependent upon glacial erosion, though some within the glacial boundary (including those of the Olean quadrangle) may to a slight degree be modified by glacial action.

There are within the glaciated region several low tracts leading across the continental divide in western New York, northwestern Pennsylvania, and northeastern Ohio. A few occur also in the district north of Cattaraugus Creek, in western New York, and they are not rare between French Creek and the Allegheny in western Pennsylvania, as well as in the districts farther south and west. They may in some cases be old lines of drainage, but in most cases they probably pass over old water partings. The great majority are so heavily filled with drift, the filling not infrequently being

[1] New York Geol. Survey, Fourth Geol. District, 1843, p. 225.

200 feet or more, that it is a difficult matter to locate the precise position of the old divides. The term "through-cut valleys" has been applied to them, but this seems an inappropriate name for such as have rock floors sloping in opposite directions from a concealed divide. They differ from abandoned channels, which are of somewhat frequent occurrence in the portions of the region where the drift is heavy, for in these channels the rock floor has a slope in but one direction, there being no old divides buried along their courses. Several of the abandoned channels will be discussed below.

The valleys of this hilly country present marked differences in topography. In some valleys the slopes from top to bottom have a mature aspect, while in others the upper part of the slope is mature but the lower part is gorge-like and youthful in appearance. The phenomena suggest at once that some valleys have remained below the level of stream cutting while others have been undergoing a marked trenching. In those which have been deepened the old valley bottoms are traceable as terraces along the brow of the rock gorges or canyon valleys, for the old valleys are generally broader than the new ones. In some cases, however, the new valleys occupy the full width of the bottoms of the old ones, and there is only the change in the angle of slope of the valley bluff to mark the depth reached by the old valley. There is in some valleys a series of complex terraces or rock shelves, of which one set or system stands at the brow or border of the canyon valley and the others at higher altitudes. There are also in some cases rock shelves inside the trenches of the canyon valleys. The set of terraces standing at the brow of the canyon valley is, however, a far more persistent feature than any of the others, and it is this set which receives chief attention in the ensuing discussion of drainage systems. It seems to mark a true gradation plain, formed when the stream was in a condition between degrading and aggrading its bed.[1]

Let us turn to this region for a few general illustrations of the above statements. It may be noted that in western New York and the northwest corner of Pennsylvania the gradation plains have been buried beneath the heavy accumulations of drift, so that the streams are now flowing at levels far above them. The same is true of much of the glaciated portion of the hilly region in Ohio. On the middle portion of the Allegheny drainage

[1] For use of terms see W. M. Davis: Jour. Geol., Vol. II, 1894, p. 77; also Chamberlin and Leverett Am. Jour. Sci., 3d series, Vol. XLVII, 1894, p. 255.

system gradation plains and present stream beds are more nearly coincident, but on the lower Allegheny, the Monongahela, the tributaries of these streams, the Ohio, and its southern, and smaller northern, as well as the lower courses of its large northern, tributaries the gradation plains stand above the present streams. The Ohio and Allegheny, as shown below, have been formed by the combination of several drainage systems which were more or less independent. In accord with and in support of this interpretation the slope of the gradation plains is found to be out of harmony with the present Allegheny-Ohio system, but in harmony with certain ancient systems whose extent and connections are outlined below.

CHAPTER III.

DRAINAGE SYSTEMS.

SECTION I. OHIO RIVER SYSTEM.

This great river system, with an area of over 200,000 square miles, drains all of the region under discussion except a narrow strip on the north, which is tributary to the Great Lakes. Its drainage area also extends eastward to, and in places slightly beyond, the crest of the Allegheny Mountains and southward to the border of the Gulf States. Only the part which has been glaciated or somewhat directly affected by glaciation will fall within the limits of the present discussion, and of this part space will permit the treatment of only the more salient features. The valley of the Ohio is first discussed, and then the northern tributaries are taken in succession, beginning with the Allegheny and passing westward to the Wabash.

OHIO RIVER.

RATE OF FALL.

The Ohio River, formed by the junction of the Allegheny and Monongahela at Pittsburg, Pa., and connecting with the Mississippi at Cairo, Ill., has a length of 967 miles.[1] It falls from 701 feet above tide at Pittsburg to 275 feet at Cairo, or 426 feet, which is but little more than 5 inches per mile. The fall, however, is somewhat irregular. In the first 15 miles it is about 19 inches per mile, and in the first 26 miles, to Beaver, 15 inches. From Beaver to Wheeling, 64 miles, it is reduced to about 10 inches per mile, and from Wheeling to the head of the Louisville Rapids, 507 miles, to 5 inches per mile. At the rapids a descent of 23.09 feet is made in

[1] A table exhibiting the profile of the Ohio River appears in the report of the U. S. Army Engineers on the survey of the Ohio River for 1870–71 (House Doc. No. 72, Forty-first Congress, third session, January, 1871, pp. 139–153). Corrections for elevations at important points on the Ohio are represented on a map of the State of Ohio and adjacent territory, which accompanies a report by Capt. H. M. Chittenden on the survey of the canal routes in Ohio (House Doc. No. 278, Fifty-fourth Congress, first session, March, 1896). A profile from Pittsburg to Wheeling, correcting that part of the earlier surveys, accompanies Appendix DD of Ann. Rept. U. S. Army Engineers for 1889, p. 1872. A diagram and table showing the profile of the Ohio River are in Water-Supply and Irrigation Papers of the U. S. Geol. Survey No. 44, Rivers in the United States, by Henry Gannett, pp. 41–43, Pl. V.

2.25 miles. Below the rapids, in the 367 miles to its mouth, the fall of the stream is but 3 inches per mile.

In addition to the Louisville Rapids there are several other rapids where the stream makes a descent of a few feet over rock. But these rock rapids appear, in most if not all cases, to be simply shelves on the border of channels which extend below the river bed. Through a partial filling of the valley with glacial gravel and sand the stream has been directed across the shelves or rock points on its borders. In the case of the Louisville Rapids an old channel has been traced past their south border through the city of Louisville.[1] At Letart Falls, a few miles above Pomeroy, Ohio, where there are rock rapids with about 3 feet descent, it is found by well data that the rock drops off toward the Ohio side of the valley to a level 25 feet or more below the low-water surface of the stream. Similar conditions are found at Cincinnati, Gallipolis, and Steubenville, Ohio; Parkersburg and Ravenswood, W. Va.; and Rising Sun, Ind.

The river bed presents an interesting series of shoals and riffles, separated by pools in which the water is deeper and the fall very low. The summary of the profile made by the army engineers shows 187 pools with a depth of more than 7 feet at low water, which occupy 632.5 miles, an average of 3.47 miles to each pool. In these pools the rate of fall is in some cases less than 1 inch per mile, though the usual descent is about 2 inches. At the riffles the descent seldom exceeds 2 feet per mile, but at Deadmans Riffle, 14 miles below Pittsburg, a descent of 4.41 feet is made in 0.65 mile; and at Letart Falls a descent of 3.2 feet is made within a mile; while at the rapids at Louisville there is, as above noted, a descent of 23.09 feet in 2.25 miles.

The depth of the rock floor of the Ohio beneath the level of the present stream is generally between 30 and 60 feet, though there are points in the lower course where it is known to reach 75 feet. Although several rock formations, which differ greatly in their power to resist stream corrasion, are encountered in its course from Pittsburg to Cairo, the effect on the gradient of the stream is scarcely appreciable. It appears that the present Ohio Valley had become sufficiently mature at the time of the

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[1] Data on this channel were furnished the writer by Prof. William J. Davis, of the Louisville school board, and by Messrs. John Ryan and John C. Oestrich, of the Louisville Pump Works. Data collected by C. E. Siebenthal suggest another channel north of Jeffersonville, Indiana. See Rept. Geol. Survey Indiana for 1900, pp. 359–364.

latest glacial filling to have its valley bottom or rock floor reduced to a somewhat regular and rather low gradient.

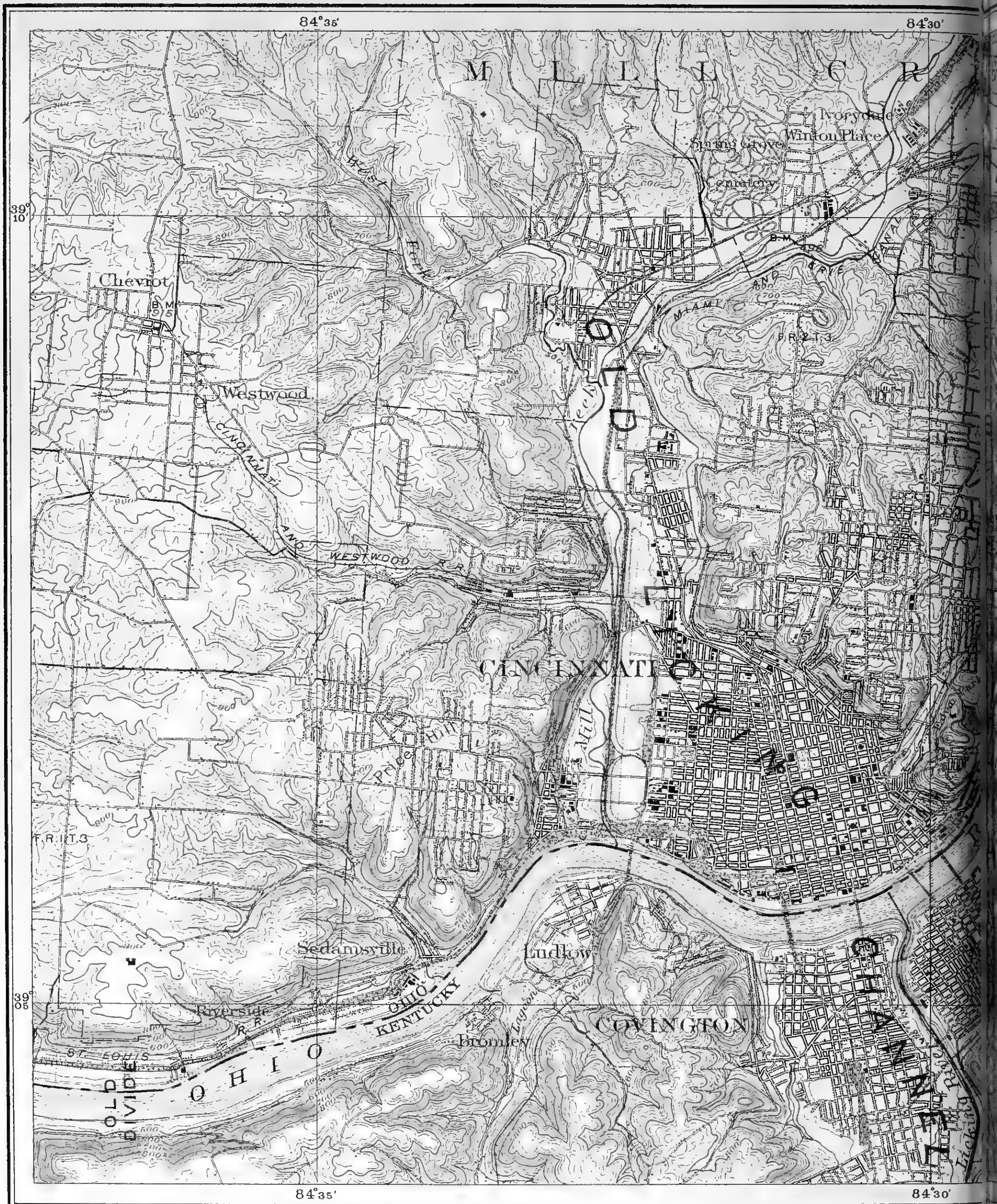
EFFECT OF ROCK RESISTANCE ON SIZE OF VALLEY.

The variable resistance offered by the rock formations has produced an appreciable effect on the size of the valley. It ranges in width from less than a mile up to 5 or 6 miles, and in depth from scarcely 100 feet up to about 800 feet. It is narrow in the deep portions as well as in its passage across hard or resistant rocks, and broad in the shallow portions, which are generally excavated in shales or other soft or easily disintegrated rocks. Where the rocks are very easily disintegrated the uplands are greatly broken down for some distance back from the immediate bluffs of the stream, thus giving the valley the appearance of being smaller than it really is; but a full restoration of the original surface in these soft formations would require decidedly more filling than in the hard formations. The effect of rock resistance is discussed in more detail below in connection with the several valleys or valley factors which were antecedent to the present Ohio.

ROCK ISLANDS IN THE VALLEY.

In addition to the rock ledges which the present stream encounters there are several noteworthy rock islands in the valley which promise to throw considerable light upon the drainage history. One at the head of the Ohio, in Allegheny, Pa., called Monument Hill, reaches a height of nearly 200 feet above the river, and is separated from the north bluff by a channel less than one-half mile in width, in which there is a gravel filling extending below the level of the present stream. Monument Hill appears to be a remnant of an old gradation plain, and the river there has simply cut a double channel in its old bottom.

Passing over "McKees Rocks," which stand on the south side of the stream about 6 miles below Pittsburg, and seem once to have been connected with the north bluff, the next prominent rock island is opposite Steubenville, Ohio. This island reaches a height of 450 feet above the river, but is crossed by an old gradation plain of Harmons Creek, an eastern tributary of the Ohio, which stands about 350 feet above the river. The present stream occupies only the channel on the west side of the island. The length of the island is about 2 miles, and the width is scarcely half a



TOPOGRAPHIC MAP SHOWING DRAIN

Contour

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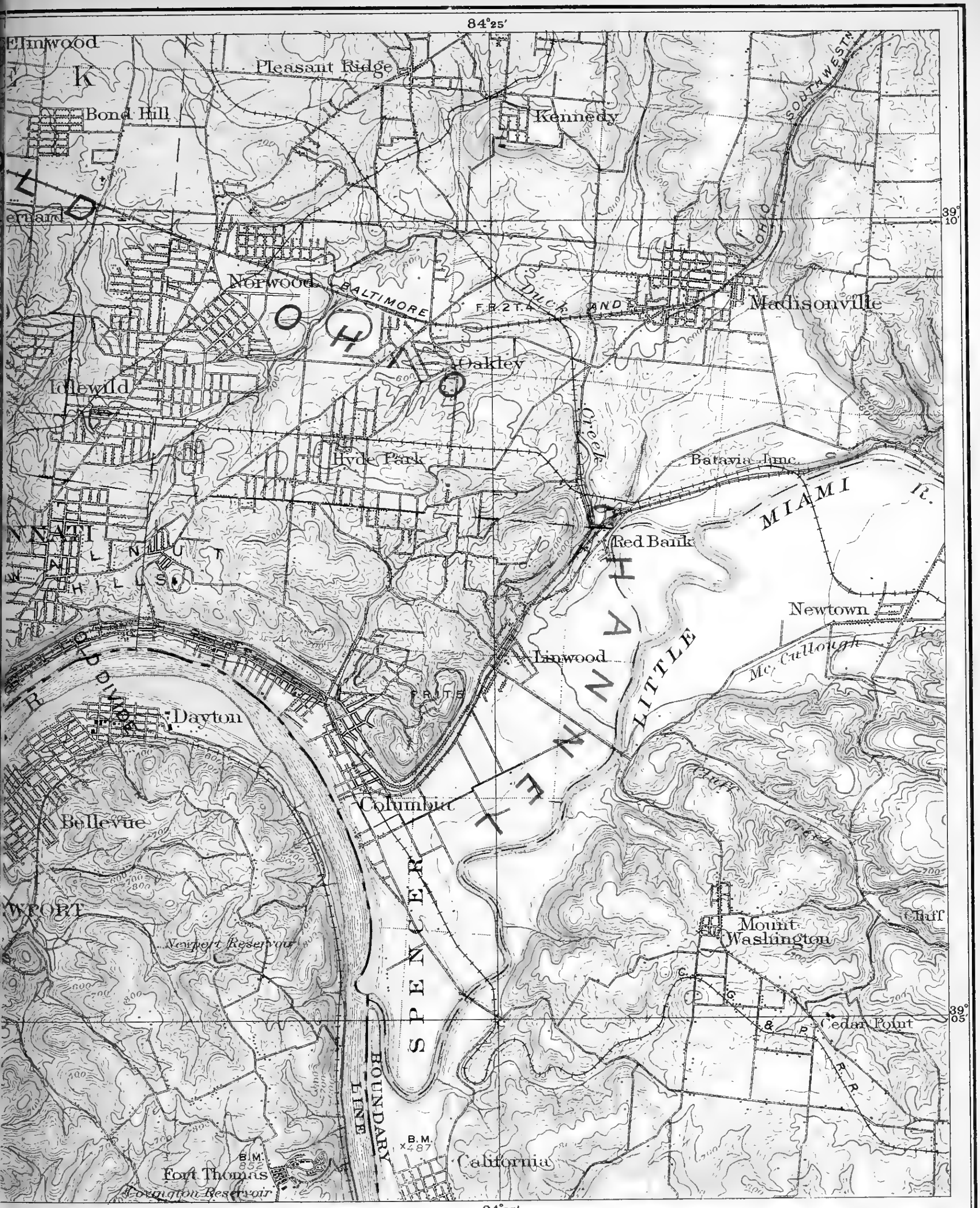

JULIUS BIEN & CO. LITH N.Y.

FEATURES NEAR CINCINNATI, OHIO

3 4 5 Miles

3 4 5 Kilometers

20 feet

level

TOPOGRAPHIC MAP SHOWING DRAINAGE FEATURES NEAR CINCINNATI, OHIO

5 Miles

5 Kilometers

Contour interval 20 feet

JULIUS BIEN & CO. LITH. N.Y.

mile. Like Monument Hill, it is separated from the uplands east of the river by a narrow channel, less than half a mile in average width, with a gravel filling that extends down about to river level. The cause for the excavation of a double channel at this place is not yet apparent.

Opposite the mouth of Middle Island Creek, which enters the Ohio at St. Marys, W. Va., a rock island is found on the Ohio side which stands about 300 feet above the river. It is separated from high land on the north by a channel about one-third of a mile in width, whose surface is only 50 to 60 feet above the river, and is still utilized at extreme high water. It is probable that this island has been cut off from the uplands on the north by the encroachments of the Ohio River. The stream is now encroaching upon the east side of the island, and it appears formerly to have made an ox-bow curve, which encroached on its west side.

At the mouth of the Little Kanawha River, at Parkersburg, W. Va., there is a rock island which stands about 180 feet above the river. It is separated from the east bluff by a gravel-filled valley about one-half mile wide, whose surface is 75 to 80 feet above the river. The width of this channel is only one-third as great as that occupied by the Ohio west of the island, but about the same as the valley of the Little Kanawha south of the island, and it may have been excavated by the latter stream. Well data suggest, though they are not full enough to demonstrate, that the abandoned channel has a lower rock floor than the present channel of Little Kanawha. This being the case, the island has probably been cut off from the upland south of the Little Kanawha River. Encroachments, either by the Little Kanawha or by the Ohio, may have opened a passage for the present course of the stream.

An island or irregular group of hills in the north part of Cincinnati, known as Walnut Hills, stands 300 to 400 feet above the river and separates a broad abandoned channel on the north from the narrower present valley of the Ohio on the south (see Pl. V). At the west it is bounded by Mill Creek Valley. The Walnut Hills island apparently once had connection with the uplands south of the Ohio, between the Licking and Ohio rivers, but through a diversion of the Ohio has been separated from those uplands. In this connection it may be remarked that the old Ohio appears to have taken a northward course from Walnut Hills to the Great Miami near Hamilton, Ohio, and to have received the Licking through the lower

course of Mill Creek (reversed), along the west border of Walnut Hills. The triangular tract lying between Mill Creek, Great Miami River, and Ohio River, and comprising several townships of Hamilton County, Ohio, is also surrounded by stream channels as completely as Walnut Hills, and apparently for the same reason, the present course of the Ohio from the mouth of Mill Creek to the mouth of the Great Miami being comparatively new. This matter is discussed more fully later (pp. 116–118).

A few miles below the mouth of the Great Miami River a rock island appears on the Kentucky side, and rises about 200 feet above the river. It is separated from the east bluff by a channel nearly one-fourth mile in width which stands scarcely 100 feet above the stream. Well data indicate that its rock floor is above river level. The island seems to have been cut off from the east bluff by the Ohio, probably because glacial deposits filled the main channel sufficiently to give the stream opportunity to flow on each side of the land which forms this island. These deposits filled the main channel in that vicinity to a height of 150 to 200 feet above the stream.

Immediately above the mouth of the Kentucky River, and back of the city of Carrollton, Ky., there is an island or prominent group of hills standing 200 to 300 feet above the Ohio, and now separated from the uplands to the east by a gap one-half mile wide that has been filled with glacial deposits to a height of 100 to 150 feet. This separation was probably effected by the encroachments of the Ohio and Kentucky rivers. The gap is much narrower than the valley of either the Ohio or the Kentucky, and this seems to indicate that it is not an old line of drainage.

Just below Madison, Ind., there is a rock island nearly 300 feet in height, separated from the north bluff by a channel only half as wide as the present stream. This channel, though now above the reach of the river, may have been utilized down to comparatively recent times. The opening of the channel was perhaps begun by a small tributary of the river which now enters just above the island, but a fully satisfactory interpretation has not been made.

Some of the most conspicuous of the island-like uplands are found where the Ohio leaves the resistant conglomerate Coal Measures and enters the friable Coal Measures. These are well shown on the Owensboro topographic sheet (Pl. VI, in pocket), and have been discussed in some detail

by Veatch.[1] From Rockport the main channel, with a width of $2\frac{1}{2}$ to 4 miles, takes a southward course to Owensboro, while a narrower channel, known as Lake Drain or Lake Plain, leads westward and connects with the lower course of Little Pigeon Valley through a channel which is reduced at its narrowest place to a width of about two-thirds of a mile. The island inclosed by these two channels and the lower course of Little Pigeon Creek rises barely to the 500-foot contour, while the Lake Drain channel falls slightly below 400 feet. The river at Rockport is about 345 feet at low water, or only 50 feet below this channel, while at the highest floods it passes through the channel. Another much smaller island, known as the Bon Harbor Hills, appears on the Kentucky side of the river west of Owensboro, and stands in the midst of the broad valley. It rises slightly above the 500-foot contour. The channel back of it falls a little below the 400-foot contour, having very nearly the same altitude as the Lake Drain channel. There is some uncertainty as to the interpretation of this peculiar drainage. The Bon Harbor Hills are separated from uplands on either side by such broad channels, their width in each case being nearly 3 miles, that this hilly tract seems likely to have been an isolated one for a long period. But the hills back of Rockport appear to have become separated in comparatively recent times from the uplands to the north. Possibly the separation took place after the partial filling of the Ohio Valley with loess. It will be observed that the local divides are broken down in that vicinity to an altitude so low that but a slight amount of valley filling would be necessary to make it possible for a stream to be diverted across them. There are several island-like tracts along the borders of the Ohio Valley west of the limits of the Owensboro quadrangle, one of which, near Shawneetown, Illinois, is as conspicuous as either of the tracts shown in this quadrangle, but the majority are low and of small area. The history of their development is not as yet understood.

This somewhat hasty sketch of the present valley leaves untouched a number of important features which throw light upon the development of this great river, and these will now be considered. The several antecedent drainage systems are taken up in order, beginning with the Upper Ohio and passing westward to the lower course of the river.

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[1]Arthur C. Veatch: Jour. Geol., Vol. VI, 1898, pp. 257–272.

UPPER OHIO OR OLD MONONGAHELA SYSTEM.

THE OLD DIVIDE.

For some years it has been considered highly probable that the Ohio has been thrown across an old divide somewhere on the projecting portion or "Panhandle" of West Virginia, but the precise position of the divide has remained in question. It has also been held as probable that the portion of the Ohio above this supposed divide, together with the Monongahela and the lower part of the Allegheny, had their former discharge northward, along a line leading through the Beaver and Grand river valleys of western Pennsylvania and northeastern Ohio, to the basin of Lake Erie, forming what has been aptly termed the old Monongahela system of drainage, the Monongahela being the main affluent.[1] The apparent extent of this old drainage system is indicated in fig. 1.

The portion of the Ohio Valley in the 80 miles along the Panhandle and for 50 miles farther down receives no large tributaries, the sources of the streams, from both Ohio and West Virginia, being usually within 25 to 30 miles of the river. This feature of itself should arouse suspicion that this tract has been the headwaters of old drainage systems. An examination of the altitudes of its bluffs and of the bordering uplands confirms the suspicion, for they are found to be higher than the bluffs and the uplands bordering the Monongahela to the east and the Muskingum to the west, and

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[1] The following reports and papers discuss or touch upon this subject:

Discovery of the preglacial outlet of the basin of Lake Erie into Lake Ontario, by J. W. Spencer: Second Geol. Survey Pennsylvania, Rept. Q^4, 1881, pp. 357–406, especially pp. 387 and 405–406. Same paper appears in Proc. Am. Philos. Soc., Vol. XIX, 1882, pp. 300–337.

Preglacial drainage and recent geologic history of western Pennsylvania, by P. Max Foshay: Am. Jour. Sci., 3d series, Vol. XL, 1890, pp. 397–403.

Pleistocene fluvial plains of western Pennsylvania, by Frank Leverett: Am. Jour. Sci., 3d series, Vol. XLII, 1891, pp. 200–212.

Further studies of the drainage features of the Upper Ohio Basin, by T. C. Chamberlin and Frank Leverett: Am. Jour. Sci., 3d series, Vol. XLVII, 1894, pp. 247–283.

Origin of the high terrace deposits of the Monongahela River, by I. C. White: Am. Geologist, Vol. XVIII, 1896, pp. 368–379.

Descriptions of terraces in that region may be found in the following reports and papers by J. J. Stevenson: Second Geol. Survey Pennsylvania, Repts. K, 1876, pp. 11–19, and K^3, 1878, pp. 251–263; Am. Jour. Sci., 3d series, Vol. XV, 1878, pp. 245–250; Proc. Am. Philos. Soc., Vol. XVIII, 1880, pp. 283–316. Also in the following reports and papers by I. C. White: Second Geol. Survey Pennsylvania, Rept. Q, 1878, pp. 9–17; and Rept. Q^2, 1879, pp. 10–20; Am. Jour. Sci., 3d series, Vol. XXXIV, 1887, pp. 374–381; also discussions of drainage features incorporated in the detailed geology of the several counties of western Pennsylvania covered by Repts. Q, Q^2, Q^3, and Q^4 of the Second Geol. Survey Pennsylvania.

yet are located in similar rock formations. The uplands also show an increase in height in passing down the Ohio from western Pennsylvania to the southern end of the Panhandle near New Martinsville, W. Va., the altitude of local divides between the tributaries in western Pennsylvania being about 1,300 feet, with occasional points 1,400 feet within a few miles back from the river, while in the vicinity of New Martinsville the divides attain an altitude of fully 1,400 feet on the immediate borders of the river and about 1,600 feet within a few miles east. Below New Martinsville the altitude declines rapidly, falling to 1,000 feet or less in the 50 miles to Marietta.

The trend of the tributaries also suggests a reversal of drainage along the Panhandle. From the most elevated parts, near New Martinsville, northward to the end of the Panhandle, they show a decided tendency to point up the valley at their junction with the Ohio, as may be seen by reference to fig. 2.

If, therefore, attention were given simply to altitudes of bordering uplands and to the trend of the tributaries of the Ohio, the old divide would be located near New Martinsville. It was from these criteria that this location of the divide was suggested by Chamberlin and the writer in 1894.[1] While this still appears to have been an early divide, subsequent study of the gradation plains and valley deposits has led to the impression that the divide had migrated before the establishment of the present drainage. The gradation plains along the Panhandle show an exceptional intricacy. Instead of a single prominent system of gradation plains, such as is commonly displayed in the Upper Ohio region,

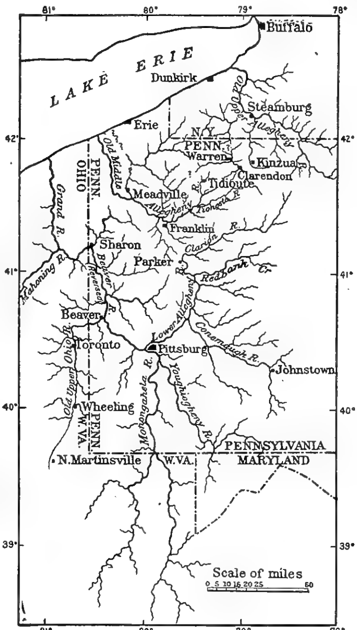

FIG. 1.—Probable preglacial drainage of the Upper Ohio region. (Chamberlin and Leverett.)

[1] Am. Jour. Sci., 3d series, Vol. XLVII, 1894, p. 253.

there are rock shelves and remnants of old valley floors on the border of the Ohio at all levels from about 1,050 feet above tide down to about

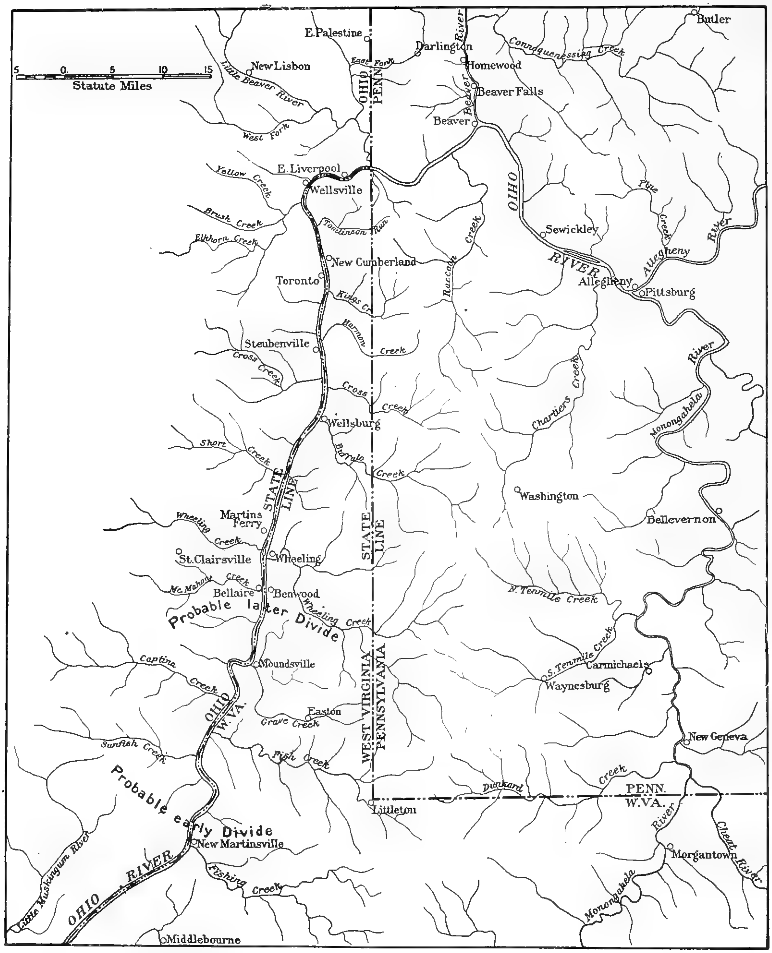

FIG. 2.—Map of part of the Upper Ohio drainage system near the supposed old divide.

800 feet. The full correlation will involve more accurate measurements and a closer study of rock textures and other features than has yet been

attempted. The writer can at best present only an imperfect and tentative interpretation. The features may perhaps be best discussed by beginning at New Martinsville, where the divide was first located, and passing from there up the Ohio to the mouth of the Beaver.

Although the trend of the tributaries and the high altitude of bordering uplands near New Martinsville suggest that the divide at one time stood near the site of that village, it evidently had become shifted to the north when the best-defined system of gradation plains of that region was formed. Fishing Creek, which enters from the southeast at New Martinsville, and Fish Creek, which enters from the east 14 miles farther up the Ohio, have a well-defined gradation plain which is in harmony with that on the portion of the Ohio below New Martinsville, and which is too low to permit of northward discharge. On Fish Creek at Littleton, W. Va., about 30 miles from the Ohio, the gradation plain stands only 930 feet above tide, while at the mouth it is not far from 825 feet. On Fishing Creek observations were made only near its mouth; the gradation plain there is about 800 feet above tide, and this plain is found to continue down the Ohio with gradual descent.

The first place above New Martinsville where features occur that suggest a change or disturbance of drainage is at the series of sharp curves in the Ohio Valley below Moundsville, W. Va., 8 to 12 miles above the mouth of Fish Creek, where the stream describes a letter S in its curves. But these curves do not seem to be accompanied by any features that make evident the crossing of an old divide. The height of the bluffs does not appear to differ from that of neighboring parts of the valley above and below; the width of the valley is also as great as the average width in that region. Furthermore, just above Moundsville, on the east side of the Ohio, a rock shelf capped with gravel appears at an altitude about 250 feet above the river, or 850 to 860 feet above tide, which seems to fit in well with the gradation plains farther down the valley. There is, however, one feature which seems to suggest a divide below Moundsville. There is a remarkably high gradation plain on Grave Creek, a tributary which enters at Moundsville from the southeast. Its altitude at Easton, only 8 miles from the Ohio, is 1,017 feet above tide, as estimated from the railway station, and it is capped by a deposit of gravel several feet in depth. Four miles below and almost in sight of the Ohio

its altitude by aneroid is 975 feet, or 125 feet above the system that has been traced up to this point along the Ohio. Probably it belongs to an older stage of drainage development, and perhaps to a north-flowing system. If the latter be true these curves in the Ohio are probably at the place where an old divide has been crossed or a piracy in favor of the western system had taken place. This question may perhaps be considered to better advantage after features farther up the Ohio have been discussed.

On the tributaries which enter above Moundsville, and also along the bluffs of the Ohio, rock shelves which appear to be remnants of old gradation plains are conspicuous at much higher levels than have been noted farther down the stream. The highest have an altitude of about 1,050 feet, and others about 1,000 and 960 to 975 feet. The altitudes here given pertain to the part of the valley near Wheeling, just above Moundsville. Farther north they become lower, being between 965 and 870 feet at the mouth of Beaver River. The remnants above 1,000 feet are not so conspicuous as those at about that level or slightly lower. As the series declines from south to north it seems probable that the gradation plains are the product of a northward-flowing drainage line which had deepened its valley to about 965 feet at Bellaire and Wheeling before reversal took place. The gradation plain near these cities, which stands at about 1,000 feet, probably connects at the mouth of the Beaver with one standing about 965 feet above tide, and at intermediate points includes the 990-foot terrace on Buffalo Creek back of Wellsburg, and the 975-foot terrace on the borders of the Ohio near New Cumberland, W. Va. The gradation plain which stands at about 965 feet opposite Bellaire and Wheeling probably connects with the 870-foot terrace at the mouth of the Beaver, and includes the 960-foot terrace at the mouth of Short Creek and the 925-foot terrace at the mouth of Yellow Creek. Probably the north-flowing system had cut down far enough before reversal took place to form a terrace south of Wellsburg which stands at about 930 feet and a terrace of similar height near the mouth of Cross Creek, south of Steubenville.[1]

[1] It should be remembered that nearly all of these measurements of terraces have been made with a barometer, and are consequently only approximations to the real altitudes. The elevations at neighboring points may differ a few feet less or a few feet more than these figures indicate. In the case of the terrace in the northern part of Wheeling the writer had opportunity to compare an aneroid reading with an accurate survey made for the Wheeling Terminal Railway, which has tunneled beneath this terrace, and found that the difference was only 9 or 10 feet; the altitude given by the railway survey being 992 feet, and by the barometer 1,001 or 1,002 feet.

From an examination of these gradation plains it appears probable that the divide between the old systems was somewhere south of Bellaire at the time the present Ohio was formed. Whether it was between Bellaire and Moundsville or at the curves of the Ohio below Moundsville may not be easy to determine. There are features which suggest that it may have been within 2 miles south of Bellaire, at the place where the high ridge south of McMahons Creek comes to the river bluff from the west. A similar high ridge sets in on the east bluff, separating Boggs Run, a north-flowing stream, from Cemetery Run, a south-flowing stream, and leads thence eastward to form the local divide between Wheeling and Grave creeks. Within 2 or 3 miles of the river this ridge attains an altitude of 1,350 to 1,400 feet, and is nearly 1,200 feet at the river bluffs. In addition to its prominence, there is also a difference in drainage features on opposite sides of the ridge, which may favor the view that it constituted an old divide, though not necessarily a very long-continued one. South of the ridge the uplands generally show a greater dissection than to the north, such as would result from connection with the system of drainage to the south, which, as shown by the gradation plains of Fish and Fishing creeks, is more than 100 feet below that of the gradation plains immediately north of this ridge. There is, however, south of this ridge the gradation plain on Grave Creek, which stands so high as to suggest that it once belonged to the north-flowing system. There is also the fact that the Ohio Valley is exceptionally large just below this ridge, as if the strata there were very weak in their resistance to erosion. In the present state of knowledge, therefore, it can scarcely be decided whether the divide at the time the Ohio was established was at the ridge above Moundsville or at the curves in the Ohio below that city. Possibly it stood for a time at the curves below Moundsville, and was shifted by stream piracy to the ridge above that city. Indeed, as previously indicated, the divide may have migrated northward, through stream piracy, from the elevated country near New Martinsville to the points in question. An inspection of the map will show that Moundsville seems to be in the midst of an old drainage system, rather than at an old divide. To place a divide there certainly gives to the section between Moundsville and New Martinsville the appearance of a truncated drainage system, but to place the divide near New Martinsville, either above or below Fishing Creek, gives a natural appear-

ance to both the northeast and the southwest system, and assigns to piracy no more than might be expected of it, in view of the fact that the southwest system was at least 100 feet the lower.

In the portion of the Ohio Valley between Moundsville and the mouth of the Beaver there are very few rock shelves or remnants of old fluvial plains at levels below those which appear to belong to the old north-flowing system, but on the tributaries rock shelves are present at all levels as incidents of the cutting down of their valleys. The general absence of rock platforms or terraces along the main valley may be assigned to the increased volume of the united stream. The most conspicuous of the rock terraces formed after reversal is found north of New Cumberland, W. Va. It stands about 100 feet lower than any of the gradation plains of the north-flowing system in that vicinity, being only 200 feet above the river and 835 feet above tide. It is preserved for a distance of nearly a mile with a width of 30 to 40 rods, and carries a few feet of gravel on its surface. In gullies which cut into this gravel Unio shells in large numbers occur, which have the weathered appearance to be expected if they are native to this old river bottom.[1] The gravel was evidently deposited by a stream flowing southward in the present direction of the Ohio, for it contains material of glacial derivation brought down from the glaciated districts to the north.

THE NORTHWARD OUTLET.

The question of a northward outlet for the Upper Ohio, Monongahela, and much of the Allegheny drainage through the Beaver was raised by Spencer nearly twenty years ago, being presented as a working hypothesis in connection with a general discussion of the origin of the lower Great Lakes.[2] Evidence in support of this hypothesis was brought forward by Foshay in 1890.[3] He called attention to the great breadth of the main gradation plain on the Beaver, to the apparent northward slope of the rock floor, and to the occurrence of potholes on this rock floor which appear to have been formed by a north-flowing stream. His discussion was limited

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[1] For notes on the occurrence of Unio shells on a terrace of the Monongahela at a similar height above the stream, see Stevenson's paper in Am. Jour. Sci., 3d series, Vol. XV, 1878, pp. 245–250.

[2] Proc. Am. Philos. Soc., Vol. XIX, 1882, pp. 330–337, with maps; also published as an appendix to Rept. Q^4 of Second Geol. Survey Pennsylvania, 1881, pp. 357–406. See pages 387 and 405–406 for this reference.

[3] Am. Jour. Sci., 3d series, Vol. XL, 1890, pp. 397–403.

mainly to the southern end of the Beaver Valley, since the gradation plain there is but little obscured by glacial deposits, though the interpretation of northward drainage was extended to the Lake Erie Basin by way of the Mahoning and Grand River valleys, and was applied to the rock floor beneath the present stream as well as to the high-level terraces. Soon after the publication of this paper the present writer discussed the nature of the evidence and dissented from that part of the interpretation which assigned a northward drainage for the channels that are buried beneath the present streams,[1] while admitting the force of the evidence of the high terraces in favor of northward drainage.

In a paper prepared in 1894, Chamberlin and Leverett[2] discussed this outlet, together with other features in the Upper Ohio region. The evidence was thought to favor a northward discharge through the Beaver prior to the excavation of the deep trench in which the lower portion of the river now flows, but the interpretation of northward drainage through buried channels was shown to be incorrect.

Two years later I. C. White discussed this outlet in connection with a paper on the terrace deposits of the Monongahela River; he considered it a "pretty surely established" line of discharge; but, like Chamberlin and Leverett, he restricted the northward discharge to a time previous to the opening of the deep trenches of that region.[3]

Turning to the Beaver outlet, we find that a gradation plain a mile or more in average width extends the whole length of the Beaver River and descends northward from about 870 feet at the mouth to about 810 feet at the head of the river, or a fall of 60 feet in a distance of 25 miles in the reverse direction from the present flow of the stream. From the head of the Beaver, at the junction of the Mahoning and Shenango rivers. the gradation plain does not maintain so great a breadth, on either the Mahoning or the Shenango, as that presented by the Beaver. On the Mahoning, which is the line of continuation suggested by Spencer and adopted by Foshay, the breadth is reduced near the Pennsylvania-Ohio line to less than one-third of a mile, and the bordering uplands there become very prominent, with an altitude of about 400 feet above the river. On the Shenango there is a

[1] Am. Jour. Sci., 3d series, Vol. XLII, 1891, pp. 200–212.
[2] Idem, Vol. XLVII, 1894, pp. 247–283.
[3] Am. Geologist, Vol. XVIII, pp. 368–379, December, 1896.

similar constriction at the very mouth of the river, just below Newcastle. Hills 300 to 400 feet in height are separated by a channel scarcely one-third of a mile wide at the level of the river, which is not far from the level of the gradation plain. Between these two valleys there is an abandoned channel leading north from the Mahoning at Edenburg, Pa., to the Shenango at Harbor Bridge, 4 miles above Newcastle, and this is a little wider than either of the other channels, though only about half as wide as the gradation plain on the Beaver. The continuation of the channel northward up the Shenango is in a valley one-half to three-fourths as wide as that of the Beaver gradation plain. From the Shenango at Sharon, Pa., there is an abandoned channel running westward to the Mahoning at Youngstown, Ohio, from which point a broad valley opens northwestward into the Grand River Basin, and this in turn opens into the Lake Erie Basin.

Since the constricted portions of the Mahoning and Shenango valleys may appear to oppose the hypothesis of a discharge of the old Monongahela system through them, they will be considered before the routes just outlined are discussed.

From descriptions given by White[1] it appears that the rocks forming the Carboniferous conglomerate measures are exceptionally soft for a few miles along the Beaver Valley, below the junction of the Mahoning and the Shenango, where the gradation plain is broadest, but contain firm and resistant beds of considerable thickness in the constricted part of the Shenango in the vicinity of Newcastle, and also on the Mahoning at its constricted part near the State line. These beds are also very firm and resistant on the Beaver in the vicinity of Homewood, but they dip rapidly southward and soon pass below the level of the old gradation plain. They cause a notable constriction in the inner valley or trench south of Homewood, but lie mainly below the level of the broad gradation plain. The occurrence of ledges which are more firm and resistant in the narrow than in the broad portions of the old gradation plain tends to greatly reduce, if not remove entirely, the difficulty of carrying through a line of northward drainage. Concerning the variability of the upper part of this rock series White makes the following remarks:[2]

> The rock in question is most variable. Only 3 miles south from the Lawrence County line we find it 155 feet thick in the great ledge at Homewood, but in coming

[1] Second Geol. Survey Pennsylvania, Rept. Q^2, 1879. [2] Ibid., pp. 53–54.

north it gradually thins away, and where it enters the county has not more than half that thickness, while at Wampum, 4 miles above, it is still further reduced to 50 feet, and on going north along the Beaver a few miles from that point it disappears entirely as a massive rock, being reduced to a few feet of flaggy sandstone and shale.

After thinning away almost entirely on the Big Beaver near Newport, it comes in again to the north below Newcastle, and is seen at the falls of Big Run, where it is 30 to 40 feet thick and quite massive. It also retains its massive character to the northward, along the Neshannock.

As to the route pursued by the old drainage line from the head of the Beaver toward the Lake Erie Basin, the available data appear to indicate the one from Edenburg northward past Harbor Bridge to Sharon, Pa., and thence westward past Youngstown to the Grand River Basin. But as an alternative view it is suggested that there may have been more than one channel across the resistant portions of the Carboniferous conglomerate, between the head of the Beaver and Youngstown. While the main current followed the route suggested from Edenburg to Youngstown, a subordinate one may have opened a narrower but more direct channel along the Mahoning Valley. The united breadth of these channels is scarcely equal to the average breadth of the Beaver Valley. The possibility of double channels being maintained during the opening of a deep valley finds such striking illustrations in the present Ohio Valley that this view at least merits attention in the interpretation of the drainage peculiarities. The difficulties of interpretation are intensified by the presence of the glacial deposits, which have greatly obscured the valley contours and buried the gradation plains.

Although the gradation plain passes below the level of present drainage lines near the head of the Beaver, its altitude and slope may be interpreted with a fair degree of certainty by means of borings. In the abandoned valley between Edenburg and Harbor Bridge farm wells enter rock at about 800 feet above tide, or a few feet lower than the gradation plain in the north end of the Beaver Valley. In the abandoned valley between Sharon and Youngstown a boring at Hubbard enters rock at a level slightly below 800 feet. Wells in the Grand River Basin near Mesopotamia, only a few miles north from the present divide between the Mahoning and Grand rivers, reach the rock at about 650 feet above tide, and this probably marks the level of the old gradation plain. From the

level of the rock floor at these wells it appears probable that the old river entered the Lake Erie Basin at a level at least as low as the present surface of the lake, 573 feet.

EXTENT OF THE OLD MONONGAHELA SYSTEM.

The old Monongahela system appears to have embraced the entire drainage of the Monongahela, the Allegheny as far up as Clarion River, the portion of the Ohio above Bellaire, the greater part of the present drainage basin of the Beaver, and the lowland known as the Grand River Basin. The greater part of this drainage system lies outside the glacial boundary, but the trunk stream and its small tributaries northward from the southern end of the Beaver Valley are within the limits of glaciation, and the Allegheny and Ohio valleys have been filled to some extent by glacial gravel transported by streams beyond the ice margin.

The portion of the Ohio above the mouth of the Beaver, the Monongahela Valley, and the portion of the Allegheny below the mouth of Clarion River have a system of gradation plains that slope in harmony with the present lines of drainage toward the Beaver Valley. They fall less rapidly than the present streams, as is to be expected of such a system of gradation plains. Thus on the Monongahela, as shown by White,[1] the fall of the present stream is 190 feet in the 206 miles below Weston, West Virginia, while the gradation plain descends only 110 feet in the same distance. On the Allegheny the present stream falls 163 feet in 82 miles below the mouth of Clarion River, while the gradation plain descends but 120 feet in this interval. In the 26 miles from the head of the Ohio at the junction of the Allegheny and Monongahela down to the Beaver the gradation plain has a descent of about 30 feet.

At this point it seems necessary only to consider the reasons for not including in the old Monongahela system the part of the Allegheny drainage basin above the mouth of the Clarion River. These will be but briefly discussed, since the Allegheny drainage is treated in some detail farther on.

THE OLD DIVIDE ON THE ALLEGHENY.

The gradation plain which is found on the Lower Allegheny continues up the Clarion, as well as up tributaries which enter below the mouth of the Clarion. The portion of the Allegheny immediately above the mouth of

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[1] Am. Geologist, Vol. XVIII, 1896, pp. 368–379.

the Clarion presents a very narrow valley, scarcely one-third the width of the gradation plain of the Clarion and Lower Allegheny. This valley has precipitous bluffs reaching a height of about 400 feet above the stream, or nearly 250 feet above the gradation plain at the mouth of the Clarion. It seems necessary to suppose either that a disproportionately small gradation plain with high cliff borders lay in the narrow gorge, or that there has been a reversal of drainage by which a small stream that had its source just above the mouth of the Clarion and flowed northward was reversed and its valley was recut to fit a new and larger stream.

On the first supposition we naturally look to differences in the hardness of strata for a possible explanation of the differences in the size of the valley. If there has been but little change in the ancient Allegheny, we must explain the fact that a stream not less than three times the size of the Clarion excavated a valley only one-third to one-half as large. If the subsequent addition of the Upper Allegheny be granted, we must account for the fact that a drainage area about the size of the Clarion cut a valley but one-third to one-half as large.

The strata along the narrow portions of the Allegheny, from Franklin to the mouth of the Clarion, as well as for some distance above Franklin, are on the whole rather more resistant than those in which the gradation plain of the lower course of the Clarion was carved. On the Allegheny there is a considerable amount of the Lower Carboniferous conglomerate, in places reaching a thickness of 75 feet, while on the Clarion there are the more easily eroded Coal Measures sandstone and shale. The greater hardness and resistance to erosion would naturally lessen the size of the valley, though it scarcely seems adequate to produce so marked a difference. Upon turning to tributaries of this part of the Allegheny, a more decisive line of evidence in favor of a reversal of drainage is found.

The tributaries of the Allegheny above the mouth of the Clarion have channels that were not deepened to levels in harmony with a gradation plain so low as that of the Clarion. While they have normal gradients on their upper and middle courses, the streams descend by rapids and cascades to the present Allegheny. This is done from a height of about 400 feet, while the tributaries of the Clarion and of the Allegheny below the Clarion descend in this way only 150 to 200 feet. This seems to indicate that tributaries above the mouth of the Clarion formerly discharged into a stream which had not reached so low a plain as that of the Clarion.

Turning now to the bordering uplands, we find another line of evidence favoring reversal. Immediately above its junction with the Clarion the Allegheny cuts through an elevated tract which to the eastward constitutes the divide between waters flowing north and northwest into the Allegheny and those flowing south into the Clarion, while to the westward it constitutes the divide between the northward or eastward flowing tributaries of the Allegheny and the streams flowing south and west to the Beaver and the Shenango (see fig. 5, p. 135). The high divide is broken by a gap scarcely a mile wide and 500 to 600 feet in depth where crossed by the Allegheny. The altitude and relief of this divide appear to be due to its relation to drainage systems rather than to axes of upheaval, for its trend is in large part independent of such axes. That is to say, it constitutes a natural boundary between the Middle Allegheny and the Clarion-Lower Allegheny drainage basins.

The slope of rock shelves and remnants of gradation plains north from the supposed divide bring further confirmation of the hypothesis of reversal. The rock shelves which stand 375 to 400 feet above the present stream, or 1,275 to 1,300 feet above tide, near the supposed divide, show a decline of about 200 feet in the 20 miles northward to the mouth of French Creek. This rate of fall would be natural only in a small stream descending from an elevated table-land.

The combined force of all the lines of evidence is such that there seems no doubt that there was formerly a divide on the line of the Allegheny ust above the mouth of the Clarion separating the drainage of the old Monongahela system from that of the old Middle Allegheny system.

MIDDLE OHIO OR OLD KANAWHA SYSTEM.

Near the eastern border of the flat-topped crest of the Cincinnati arch the streams in the vicinity of the Ohio River have a trend which strongly suggests the former presence of a divide. Those to the east of the arch trend up the present Ohio toward the mouth of the Scioto, while those on the flat crest, from its very eastern border, lead westward down the Ohio. The position of the old divide at the border of the present Ohio seems to be very near the village of Manchester, Ohio. The valley of the Ohio presents higher bluffs in the vicinity of the supposed divide than at points above and below, and the general topographic expression seems adapted to the occurrence of a divide at the place suggested. To this is added the evidence from an abandoned northward outlet, discussed below.

Since the principal stream of the system east of the supposed divide is the Big Kanawha River, it seems pertinent to give the name Kanawha to the old system of drainage. It might also be appropriately termed the Middle Ohio system.

THE NORTHWARD OUTLET.

An abandoned channel leaves the Ohio at Wheelersburg, about 8 miles above the mouth of the Scioto, and, as shown in fig. 3, passes northward in a somewhat winding course, coming to the Scioto Valley at Waverly. That it was the course of a northward-flowing stream is attested by the presence of quartzite cobble and gravel, such as occur along the Ohio above this point. This material was derived from the headwaters of the Kanawha drainage basin.

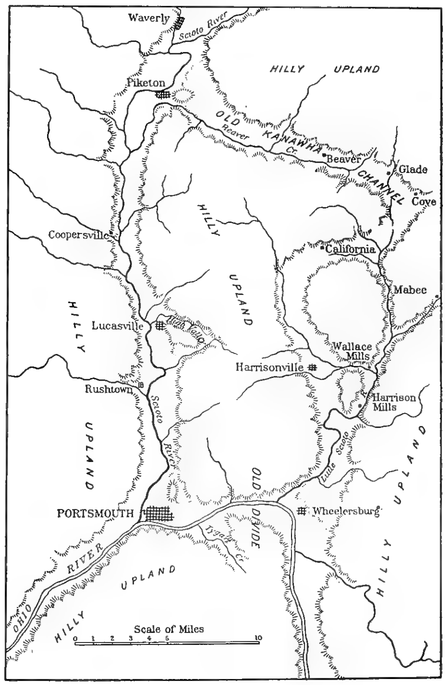

FIG. 3.—The old Kanawha drainage system in southern Ohio.

The rock floor of this old drainage line is far above the level of the present stream, being about 625 feet above tide where it leaves the Ohio, while the altitude of the present stream at that point is about 475 feet; at Waverly its altitude is fully 600 feet, while the Scioto at that point is about 75 feet lower. Its altitude corresponds with that of the system of gradation plains in that region, and its course must be determined by an examination of the gradation plains on the Scioto.

From Waverly the old Kanawha must have taken one of two courses, either northward into the Scioto Basin along the line of the present Scioto (reversed), or southward down the present Scioto Valley to the Ohio at

Portsmouth. As the latter is the present course of drainage, we naturally turn to it first.

An examination of the Scioto Valley below Waverly has brought to light an old oxbow channel immediately back of the town of Lucasville, which has about the same altitude as the channel of the old Kanawha east of that point, but which appears to have been formed by a much smaller stream than that which formed the channel of the Kanawha. Its breadth, as shown in fig. 3, is only about a half mile, while that of the old Kanawha Valley is more than a mile at its narrowest places and $1\frac{1}{2}$ miles or more at its broadest places. This small channel has every appearance of being the main if not the only line of discharge for the stream that opened it. It is such a channel as would be expected from a stream which drained only the small area that lies between Lucasville and the supposed divide near Manchester, Ohio. It certainly testifies strongly against the discharge of the old Kanawha southward from Waverly.

A similar oxbow of a small stream was found on the south side of the Ohio near Quincy, Ky., about 10 miles below the mouth of the Scioto. It, however, stands so much higher than the oxbow at Lucasville (being nearly 150 feet above its level) that it seems likely to have been abandoned at an earlier date than the Lucasville oxbow; but it may, nevertheless, have been produced by the same small stream, it being not unnatural for oxbows to be abandoned during a process of downcutting in a valley. The correlation in agency rather than the correlation in date is the important matter, and on this the two oxbow channels are in harmony, for they each appear to show the agency of a much smaller stream than the old Kanawha.

Turning now to the portion of the Scioto north from Waverly, it is found to carry a broad gradation plain similar to that of the abandoned part of the old Kanawha, which can easily be traced to the vicinity of Chillicothe, where it passes below the level of the Scioto and soon becomes deeply buried beneath deposits of glacial drift.

The writer called attention to this northward line of discharge for the middle portion of the Ohio in his report to the Director in June, 1896, and suggested that it was probably tributary to the drainage basin of the Saint Lawrence.[1] In a paper prepared a few months later[2] this interpretation was

[1] Seventeenth Ann. Rept. U. S. Geol. Survey, Pt. I, 1896, p. 61.

[2] Changes of drainage in southern Ohio: Bull. Denison Univ., Vol. IX, Pt. II, 1897, pp. 18–21.

qualified and four possible courses were suggested for the discharge from the southern end of the Scioto Basin: First, southward, down the Scioto from Waverly to the Ohio and thence down the Ohio; second, northward, along the axis of the Scioto Basin to Lake Erie; third, northwestward across western Ohio, along one of the several deep valleys brought to light in that region by the oil and gas wells, eventually to either the low tract on the lower course of the Wabash or the basin of Lake Michigan; fourth, northeastward past the Licking reservoir and an old valley east of Newark to the Muskingum at Dresden, and thence northward along or near the present valleys of the Muskingum, Tuscarawas, and Cuyahoga to the basin of Lake Erie at Cleveland.

It was since that paper was prepared that the writer discovered the oxbow channel back of Lucasville, above noted, which seems to testify strongly against the southward discharge down the Scioto and renders that line an improbable one. The writer also has since found decisive evidence against the suggested northeastward line, in the presence of an old divide now crossed by the Tuscarawas between Zoar and Canal Dover, Ohio, discussed farther on.

Concerning the relative probabilities of the remaining two lines but little has been determined. If the present surface is examined both the northward and northwestward courses seem beset with difficulties. The northward route along the axis of the Scioto Basin encounters a general rise in the bordering plain of about 200 feet in the 100 miles between the south end of the basin, near Chillicothe, and the continental divide near Marion, north of which there is an even greater descent to the Lake Erie Basin. If the course of drainage was northward across the divide, and if the divide has not suffered recent uplift, there must have been channeling in it to a depth of about 300 feet. That an axis of uplift exists in this part of the continental divide is shown by the arching of the rock formations over it; but its extent and its date are not yet determined.[1]

The northwestward route leads across the limestone belt on the west side of the Scioto Basin, whose general level is about 200 feet above the continental divide at the north end of the basin and 500 feet above the gradation plain near Chillicothe. To pass through that region the

[1]See Geology of Ohio, Vol. VI, 1888, pp. 57–58, 312, 316. See also the sections of rock formations from Cleveland to Marietta, and from Berlin Heights to Ironton, opposite p. 321 of same volume.

channeling would be so much greater than is required for a northward course along the axis of the basin that one can scarcely resist ruling out the northwestward course. Yet from what is found on the Lower Ohio, where the stream passes directly across the low Devonian shale area into the knobstone and sandstone formations that now stand much higher, such a ruling may be unwarranted. The presence of the low basin occupied by Lake Erie offers an additional argument in favor of the northward route. This basin would be reached by that route in less than half the distance required to reach a similar low tract in the Wabash region or the Lake Michigan Basin by the northwestward route. Each of these routes falls within regions so heavily covered with glacial deposits that the course of the channels can be traced only by means of borings, and these are so few and so poorly distributed as to be inadequate to our needs.

DEFLECTIONS OF DRAINAGE.

In changing from its old course to its present one the Kanawha system has suffered several notable deflections. The principal one is that which turned the waters southward from the Scioto Basin to the present Ohio at Portsmouth, and thence westward into the Lower Ohio; a second deflection carried the waters of the Kanawha westward from Wheelersburg (where the old Kanawha turned north from the Ohio) to Portsmouth, thus abandoning the part of the old channel between Wheelersburg and Waverly; a third turned the Kanawha north from the east end of Teays (or Teazes) Valley (near St. Albans, W. Va.) to the Ohio at Point Pleasant, thus abandoning Teays Valley from St. Albans to Huntington. It is not certain that these changes were made at one time, though they appear to have been made in close succession. The second and third appear to have been nearly contemporaneous from the fact that the abandoned channels are each at the level of the main gradation plain, about 150 feet above the present level of the Ohio River. It seems probable that the deflection to the Lower Ohio may have preceded the deflection from Wheelersburg to Portsmouth, there being apparently no sufficient reason for the latter to have taken place until the western line of discharge from Portsmouth had been opened.

The change which resulted in the deflection of the old Kanawha into the Lower Ohio seems to have required considerable erosion in the vicinity of the old divide, even though it occurred when the streams of the old Kanawha system were flowing in valleys whose depth was much less than

that of the present Ohio. The removal of the col near Manchester, at the head of the southwestern tributary, probably represents but a small part of the work accomplished, for the channel of this tributary seems to have been enlarged throughout its length of fully 50 miles. There was apparently, also, some enlargement of the headwater portion of the old west-flowing stream beyond the divide, for the Ohio River bluffs are exceptionally abrupt for a few miles west from Manchester.

The change to the present course from Wheelersburg to Portsmouth seems to have required but little work. The principal cutting appears to have been in the 3 or 4 miles between Wheelersburg and the mouth of Tygarts Creek, a north-flowing stream which reaches the Ohio just above Portsmouth and which apparently connected there with the stream above noted that came in from the southwest. The ridge crossed east of Portsmouth is prominent on each side of the Ohio, its altitude being about 300 feet above the old Kanawha channel. But the space above the bluffs is about 1½ miles, and this may have contained a sag or broken-down part of the ridge, so that the cutting need not have been so much as the height of the present bluff would indicate. The maximum allowance for cutting can not exceed 300 feet in depth, 1½ miles in width, and 3 miles in length, and the probabilities are that the cutting was much less than that amount.

The abandoned line of discharge for the Kanawha River between St. Albans and Huntington, W. Va., known as Teays Valley,[1] was brought to notice some years ago by White[2] and discussed more fully later by Wright,[3] under the name of Teazes Valley. The rock floor of this abandoned valley stands 630 to 650 feet above tide, or 145 to 165 feet above the Ohio at Huntington, W. Va., where it connects with that stream. Measurements with Locke level show that the rock floor at the east end near St. Albans has an altitude of 630 to 640 feet, while at the mouth of the Big Sandy River, just below Huntington, the rock floor of its broad terrace has an altitude of 630 feet. Between these places points were found where the rock floor reaches 650 feet, but it is not certain that the lowest part of the channel floor was exposed. The old gradation plain is now covered with a thick deposit of silt, whose surface stands 700 to 720 feet above tide, or 60 to 80 feet above the rock floor. This silting was sufficient to build up the

[1] Geologic Atlas U. S., folio 69, Huntington, W. Va.
[2] Appendix to Wright's Glacial Boundary in Ohio, 1884, p. 84.
[3] Bull. U. S. Geol. Survey No. 58, 1890, pp. 86–88.

valley to a level as high as low cols in the district north of it, thus making it possible for a stream to take a new course without having to open a channel. Not only the Kanawha but Hurricane Creek and Guyandot River (tributaries entering Teays Valley from the south) continue into channels north of that valley. The channel into which the Kanawha and Hurricane Creek were turned had gradation plains slightly higher than the rock floor of Teays Valley, measurements with Locke level showing the height of the gradation plain on the lower end of the present Kanawha, near the mouth of Hurricane Creek, to be 680 feet above tide, but as these channels had not become so filled with silt as Teays Valley, the drainage could pass into them. It is this fact of a lower line of escape that seems chiefly responsible for the diversion from a direct to an indirect course.

Between the west end of Teays Valley and the south end of the abandoned channel at Wheelersburg the old line of the Kanawha usually nearly coincides with that of the present Ohio, and its rock floor stands 150 feet above the present stream. There is, however, one deflection worthy of mention. For a few miles below the point where the Ohio passes the West Virginia and Kentucky line, the old Kanawha channel is separated from the present Ohio Valley by a narrow range of low hills. This valley, with its deposits of gravel, was noted by Lyon in an early report of the Kentucky geological survey,[1] and was described more fully by Andrews in a report of the Ohio survey.[2] By both, the gravel deposits were erroneously referred to the glacial drift. In this old channel the silt filling is but little less than in Teays Valley, the surface of the silt being 680 to 700 feet above tide, or 50 to 70 feet above the rock floor. The gravel which underlies the silt is a thin deposit resting upon the rock floor. The accompanying map (Pl.VII), which embraces a portion of the Ironton quadrangle, shows a part of this old valley and the present Ohio, with a range of hills between them. The hills occupy the interval between the mouths of White Oak Creek and Pond Run. Although they rise in places to a height of more than 100 feet above the silt filling in the old valley, they are interrupted by notches so low that small streams drain from the old valley through them to the present Ohio. It is probable that the Ohio took advantage of similar low gaps in changing from the old course to the present one.

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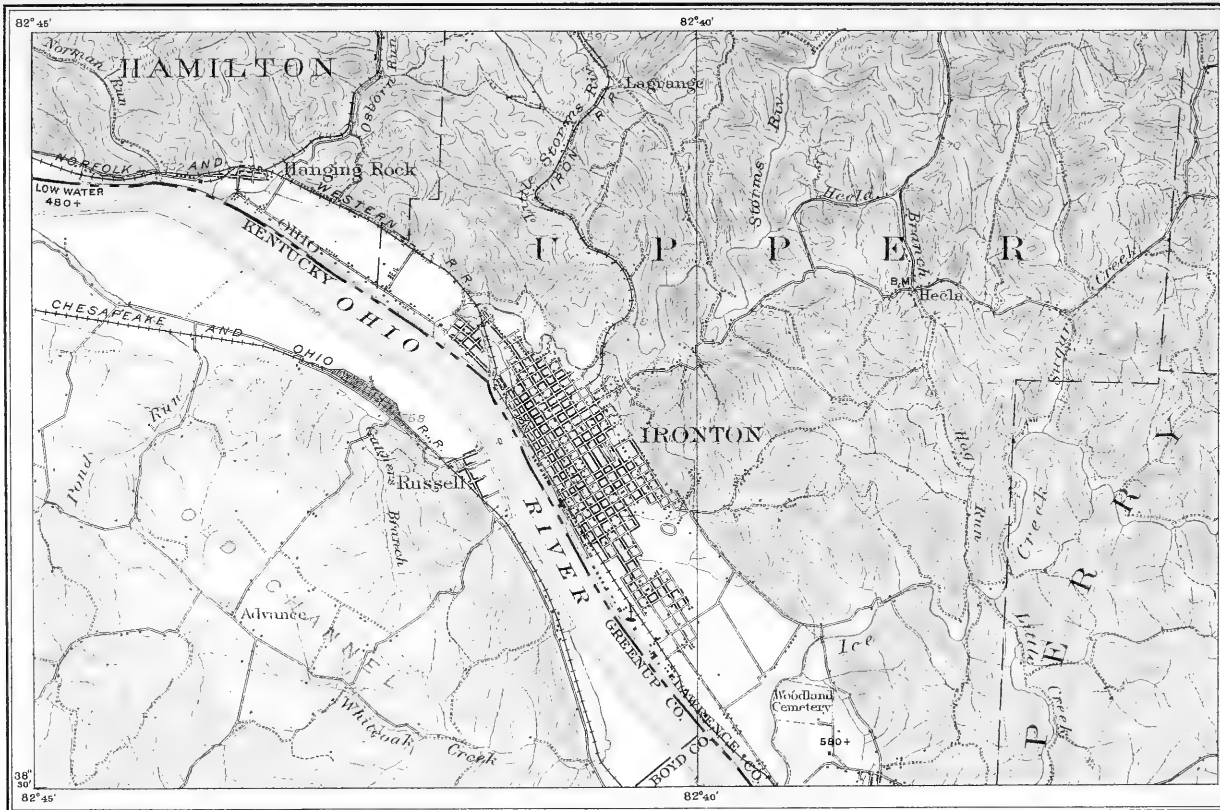
[1] Sidney Lyon: Second Geol. Rept. of Kentucky, 1856 and 1857, p. 360.
[2] E. B. Andrews: Geology of Ohio, Vol. II, 1874, p. 441.



Topography by Hersey Monroe and W N Morrill
Surveyed in 1898.

JULIUS BIEN & CO. N.Y.

Edition of Jan 1900.

DRAINAGE FEATURES NEAR IRONTON, OHIO

Scale

0 1 2 3 Miles

0 1 2 3 Kilometers

Contour interval 20 feet

Datum is mean sea level

How much of the present Ohio above the point where Teays Valley connects with it follows its old course may now be considered. Between the present mouth of the Kanawha, at Point Pleasant, W. Va., and the west end of Teays Valley, the Ohio is in a valley which for a few miles becomes so constricted as to suggest the crossing of an old divide. The width at Point Pleasant is about 2 miles, but it becomes reduced to 1½ miles in the first 8 miles below that town, and to scarcely 1 mile at Crown City, 10 miles farther down. For 10 miles below Crown City the breadth is a mile or less. The valley then gradually expands to a width of nearly 2 miles at Huntington, 15 miles farther down the river. In this narrow portion the bluffs rise abruptly to a height of 200 feet, or to about 700 feet above tide, and the uplands reach an altitude 200 feet higher within a mile or two of the river. A thick-bedded, very resistant sandstone outcrops at about 700 feet throughout much of the narrow portion, and in several places presents mural escarpments and often breaks in blocks 10 to 15 feet thick. This sandstone, no doubt, has had great influence in making the bluffs abrupt up to this altitude and in preventing a widening of the valley. Whether it fully accounts for the narrowness, or whether the narrow portion once contained a divide, the writer was unable to decide.

In passing up the Ohio from the mouth of the Kanawha to the mouth of the Little Kanawha River, at Parkersburg, W. Va., the valley of the Ohio is found to be very winding and also exceptionally broad, its width ranging from 1½ to nearly 3 miles. Throughout this interval its passage is through a region similar to that in the vicinity of Teays Valley, in which the divides have been greatly broken down, so that there are numerous cols at only 700 to 750 feet above tide. This portion of the Ohio Valley preserves but few rock shelves or remnants of a gradation plain that can be correlated with the gradation plain on the old Kanawha noted above. The tributaries, however, present remnants of a gradation plain which serve to show the height of the old valley floor above the present Ohio. They stand nearly as high as the lowest cols, being nowhere less than 660 feet above tide, and usually about 680 feet, while at the mouth of the Little Kanawha they are not far from 700 feet. The lowest observed altitude—660 feet—is found about midway between the mouths of the two Kanawhas, opposite the mouth of Big Mill Creek, above Letart Falls, West Virginia. The terraces there, by barometric measurements, stand only 120 feet above the

Ohio River. But levels more precise than barometric measurements are needed to make certain of the altitudes and slopes of the terraces in this part of the valley. The widely meandering course of this portion of the Ohio apparently resulted from the former slack drainage and degraded condition of the region Conditions were such that shiftings of the course might easily have been produced. A large area in southern Ohio north of this part of the Ohio Valley carries low divides, which afforded good opportunities for changes of drainage. The neighboring portion of West Virginia is also similarly broken down. The changes which this part of the drainage basin has experienced are being made a subject of special investigation by W. G. Tight, under the auspices of the present survey. These investigations will, it is hoped, settle the question whether the old course of drainage continued from the mouth of the Little Kanawha down to the west end of Teays Valley—that is, to the old Kanawha—or, instead, took a northwestward course, more directly toward the Scioto Basin, into which the old Kanawha had its discharge. It seems well to defer the introduction of names for the old drainage lines in this part of the Ohio until this question is settled.

From the vicinity of Moundsville, W. Va., down to the mouth of the Little Kanawha, at Parkersburg, the present Ohio appears to be following the line of an old stream, whose main gradation plain, now preserved as terraces along the valley borders, descends from about 800 feet at New Martinsville to but 700 feet at Parkersburg. The remnants are not conspicuous in the Ohio Valley, but are well preserved on many of the tributaries.

The general width of the Ohio Valley from Moundsville down to St. Marys, W. Va., is 1 to 1¼ miles, though near Ravens Rock it is less than a mile, and in the vicinity of the villages of Moundsville and New Martinsville it exceeds 2 miles. From St. Marys down to Parkersburg the width is 1½ to 2 miles. In explanation of the remarkable expansions at Moundsville and New Martinsville, J. P. Chaplin, a civil engineer residing at New Martinsville, has suggested an unusual dip of the rock strata. In the 4 miles above New Martinsville, where the valley is exceptionally wide, the strata dip eastward at the rate of 80 feet per mile, which is much greater than in the portions of the valley immediately above and below this expansion. Chaplin states that the strata at Moundsville have a marked dip southeast-

ward, though not so great as at New Martinsville, and he is inclined to refer the expansion there to the increased dip of the strata. This enlargement of the valley seems to have antedated its filling with glacial gravel of Wisconsin age. Since the filling occurred the stream has been shifting its course over the gravel bottom, and at present, in both the Moundsville and the New Martinsville expansion, it is following the west bluff instead of the east.

LOWER OHIO SYSTEM.

PROBABLE EXTENT.

Under this name will be discussed the portion of the Ohio below the old divide near Manchester, together with such of its tributaries as are concerned in the drainage and glacial history of the region. The Tennessee and Cumberland rivers, which now enter the Ohio near its mouth, are practically independent of the Ohio, since their mouths are within the Tertiary valley of the Mississippi. Green, Salt, Kentucky, and Licking rivers are the main large southern tributaries. These and the small southern tributaries have apparently suffered very little disturbance by glaciation. The northern tributaries, Little and Great Miami rivers, and the Wabash, with its main affluents, White and East White rivers, have had their drainage systems greatly modified by glaciation, so that it is difficult, if not impossible, to restore the preglacial system. It is probable, however, that a large part of the present drainage basins of these rivers was tributary to the Lower Ohio in preglacial time. Attention is called below to the question of a former northward discharge of part of the Ohio drainage basin through the Great Miami Basin.

RELATION TO TOPOGRAPHIC FEATURES.

In the portion of the Ohio below the old divide near Manchester several rock formations are crossed which have yielded very unequally to subaerial degradation, and now present a series of escarpments and basins that are more impressive as topographic features than the valley of the river. These topographic features, however, exert but little influence upon the course of the Ohio and its tributaries. They trend in line with the strike, while the Ohio takes a course more nearly in harmony with the dip of the rock formations. The river passes from the Cincinnati arch across the low Niagara escarpment, formed by the Lockport limestone, down to the basin formed in the Devonian shale and thence on through

the Knobstone escarpment at a point where it has a relief of over 200 feet above the shale basin. It then crosses a shallow basin in the St. Louis limestone, after which it passes through the prominent Kaskaskia and Conglomerate Coal Measure formations and reaches the low basin of the friable Coal Measures. Finally it traverses the elevated rim of Lower Carboniferous sandstone and limestone and enters the broad valley of the Lower Mississippi.

This disregard of topographic features is paralleled by some of the tributaries of the Lower Ohio. Green River takes a somewhat direct westward course across escarpments and basins in the formations between the Devonian and Coal Measures in a district south of the Ohio, while the East White River takes a similar course in a district north of the Ohio. Salt River passes westward across the low basin of Devonian shale into the Knobstone escarpment and joins the Ohio instead of turning northward along the axis of the low basin. The Kentucky River seems to have suffered more deflection by topographic and structural features than the tributaries just mentioned. In crossing the crown of the Cincinnati arch it makes a marked detour to the southwest, but turns back to the north along the east side of the low Niagara escarpment, as if guided by that escarpment.

While the streams of this drainage system usually pass somewhat directly across the basins and escarpments, their courses are generally marked by a pronounced breaking down both of the escarpments and of the basins in the vicinity of the stream valleys. This is especially true of the major stream, the Ohio. In the passage across the Lockport (Niagara) limestone near Madison, Ind., the immediate bluffs rise 350 to 400 feet above the stream, or 750 to 800 feet above tide, but the uplands 2 or 3 miles back reach fully 500 feet above the stream, and become still higher farther back. In the Devonian shales the Ohio bluffs are only 75 to 125 feet above the river, or 450 to 500 feet above tide, but back 20 miles from the Ohio, at the divide between this river and the East White River, the axis of the shale basin rises to an altitude of over 600 feet above tide, and a similar rise is found south of the Ohio along the axis of the basin. The Knobstone formation is much more broken or degraded in the vicinity of the Ohio than a few miles north or south of the river, as well as of lower altitude. Its highest knobs on the border of the Ohio scarcely reach 800

feet above tide, but a few miles back they rise to about 1,000 feet. There is a similar breaking down on the borders of the Ohio in each of the formations to the west. In view of this condition of the formations on the border of the Lower Ohio, there seem to be grounds for considering it a very old drainage line, whose course was adopted before the present pronounced escarpments and basins had been formed.

TERTIARY FLUVIAL DEPOSITS.

The great age of the valleys of the Lower Ohio and its tributaries is also shown by the occurrence, on high terraces bordering the canyon valleys, of deposits of sand and gravel which appear to be fluvial and bear evidence of transportation to some extent in the present direction of drainage. These deposits were long ago recognized by Cox on the borders of the Ohio in southern Indiana,[1] and by Safford on the borders of the Tennessee and other streams of Tennessee and Kentucky.[2] More recently they have been noted and described on the Cumberland, Kentucky, and Licking rivers by Miller,[3] and on the Kentucky River by Campbell.[4]

The deposits noted by Cox cap the bluffs of the Ohio near Cannelton, Ind., at an altitude of about 350 feet above the stream, or nearly 700 feet above tide. The present writer has traced them eastward or up the Ohio Valley from the points noted by Cox, and found that they are preserved in small detached remnants on the bold bluffs of the Conglomerate Coal Measures and Kaskaskia formation, on both the Indiana and the Kentucky side of the narrow river valley, as far as the eastern border of the latter formation. As now preserved, they are only 10 to 20 feet in depth, and the original thickness may have been but little more. Their altitude is above the general level of the basin which has been formed in the St. Louis limestone to the east, but in their rock constituents these deposits bear clear evidence of derivation from the cherty portion of that formation. The transportation must have been effected before the basin had been formed in the St. Louis limestone, a fact which testifies strongly to the great age of the deposits.

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[1] Tertiary deposits, by E. T. Cox: Rept. Geol. Survey of Indiana for 1871 and 1872, p. 138.

[2] The eastern gravel, by J. M. Safford: Geol. Tennessee, 1869, p. 438; see also pp. 434–437.

[3] High-level gravel and loam deposits of Kentucky rivers, by A. M. Miller: Am. Geologist, Vol. XVI, 1895, pp. 281–287.

[4] The Irvine formation, by M. R. Campbell: Geologic Atlas of the United States, folio 46, Richmond, Ky., 1898.

The deposits on the Licking and Kentucky occur on what are termed by Campbell "intermediate valleys," whose floor is about 300 feet above the present streams, and but 100 feet below the general level of the bordering uplands. Miller calls attention to the presence of pebbles from Carboniferous rocks, and notes that they are restricted to deposits on those tributaries of the Licking and Kentucky which have their sources in the Carboniferous formations. From these facts the inference is drawn that they were deposited by streams which flowed in the present direction of drainage. He has traced the deposits down the Kentucky Valley to the vicinity of Frankfort, or across the crown of the Cincinnati arch. In a letter to the writer he reports that the altitude of the deposits declines from about 900 feet in the vicinity of Irvine, Ky., to 800 feet near Frankfort. They stand, therefore, at the latter point about 100 feet higher than the deposits above noted on the Ohio, and seem likely to be of similar age.

As yet no attempt has been made to trace the deposits from Frankfort to the Ohio, but it is thought by Miller that the course will continue down the Kentucky rather than depart from that valley. The wide gaps made by basins which have been subsequently formed along the course of the Ohio will necessarily render it difficult to establish full connection between the deposits of the Kentucky and those near Cannelton, on the Lower Ohio. There seem, however, to be no reasonable grounds for doubting that there was such a connection, and the degraded condition of the valley border from the mouth of the Kentucky to the deposits farther down the Ohio seems of itself sufficient ground for inferring that the course of drainage at the time these deposits were made was that which the Ohio still pursues. So far as the writer could discover, no better course is available. A course about as direct is found in a line leading westward from Madison, Ind., along the Muscatatuck to the East White and White River, and thence down the Wabash to the Ohio. That there was an ancient westward drainage along the East White River is shown by the presence of Tertiary gravel near Shoals, Ind., that was brought in from the east. But the East White has a smaller channel than the neighboring part of the Ohio, and no channel has been discovered near Madison to connect the Ohio with the Muscatatuck Valley. It therefore seems a less favorable course than that down the Ohio.

The gap to be filled between the Tertiary deposits on the Licking and those on the Lower Ohio is still wider and seems more difficult to bridge.

It is probable that at the time these deposits were made the Licking crossed the present Ohio at Cincinnati, and, together with the section of the Ohio between Manchester and Cincinnati, continued northward at least to the vicinity of Hamilton, Ohio. Possibly it maintained a northward course, passing Hamilton along the axis of the Great Miami Basin, though it seems quite as probable that it turned southwestward to connect with the Ohio at the mouth of the Great Miami and passed from there down the Ohio and connected with the Kentucky. The drainage, as indicated below, appears to have been along the latter course for a long period before the deposition of the Illinoian drift.

GRADATION PLAINS BELOW THE LEVEL OF THE TERTIARY DEPOSITS.

As may be seen by comparing the altitude of these Tertiary deposits on the Lower Ohio and its tributaries with that of the gradation plains of the Middle Ohio or old Kanawha system, the latter are far below the former. It will also be noted that the gradation plains of the Middle Ohio system pertain to valleys which had been cut to a much greater depth than those that carry the Tertiary deposits of the Lower Ohio system. Furthermore, the gradation plains are in a much better state of preservation in the Middle Ohio system than the floor of the valleys which carry the Tertiary deposits of the Lower Ohio system. These features suggest that the gradation plains of the Middle Ohio system and the "intermediate valleys" of the Lower Ohio system are not correlatives and lead us to examine the valleys of the latter system for correlative gradation plains at levels below the Tertiary deposits.

The glacial deposits have obscured the contours of the Ohio Valley throughout much of the area between Manchester, Ohio, and Louisville, Ky., rendering it difficult to trace terraces or remnants of gradation plains on the valley borders. They have in a similar manner greatly obscured the northern tributaries of the Ohio. The southern tributaries should, therefore, afford the best field for the examination of gradation plains. These, however, have been examined only to a limited extent by the writer. Observations were carried up the Kentucky only to the mouth of Eagle Creek, about 8 miles, and up the Licking River to Grants Bend, about 12 miles. Even less attention was given to other southern tributaries.

On the Licking River no well-defined remnants of a gradation plain were found below Grants Bend; but for 2 or 3 miles in the vicinity of this

bend a gradation plain is preserved, and in places occupies about half the width of the valley. Its altitude by aneroid is 640 to 650 feet above tide, or nearly 200 feet above the stream. Its rock platform is capped with a few feet of gravel and sand, among which are pebbles derived from the Lower Carboniferous rocks that outcrop at the headwaters of the Licking. A gradation plain of similar altitude above the river is reported by the residents to be preserved at points farther up the valley. This gradation plain stands 250 to 300 feet below the neighboring uplands in a valley much narrower and more sharply outlined than that which carries the Tertiary deposits. Its relation to the uplands and also to the present drainage is similar to that of the gradation plain of the middle Ohio system, of which it is the probable correlative.

On the Kentucky River but one place was found on the lower 8 miles of the valley which seems to represent a gradation plain. This is a terrace standing on the east side of the valley opposite Lock No. 1, about 3 miles from the Ohio. Its altitude is by aneroid 175 feet above the stream, or scarcely 600 feet above tide. A northern tributary of the Ohio (Indian-Kentuck Creek), entering 4 miles below the mouth of the Kentucky River has well-preserved remnants of a gradation plain near its mouth, standing by aneroid 610 feet above tide. These seem to harmonize with the single remnant found on the Kentucky and to support the view that it represents a gradation plain.

One of the most conspicuous remnants which this region affords of a gradation plain on the immediate borders of the Ohio, and one which is rather difficult to interpret, is that of an abandoned channel which leads from Eagle Creek, now a tributary of the Kentucky River, northward to the Ohio River. It leaves Eagle Creek 2 miles west of Glencoe, Ky., and passes in a winding course to the Ohio Valley at the bend above Warsaw, Ky. It stands fully 200 feet above the Ohio, and has a width of about one-half mile.

An abandoned channel with a gradation plain of a similar height and width connects closely with this channel and continues northward, back of a range of hills east of the Ohio, to the south fork of Big Bone Creek, a stream which passes from there westward into the Ohio. This northward continuation of the abandoned channel was at first thought by the writer to indicate that the old course of drainage continued northward from the

mouth of Big Bone Creek, in the reverse direction of the present flow of the Ohio. This would bring support to a view recently advanced by Fowke,[1] that the Licking and the neighboring part of the Ohio continued from Cincinnati northward, past Hamilton, through the Great Miami Basin, and received this and other small tributaries along the line leading to Hamilton from the southwest, past Lawrenceburg, Ind. But upon further reflection and a reexamination of the locality doubt has arisen concerning the validity of this interpretation. A strong element of uncertainty is found in the fact that the part of the Ohio near the points where this small abandoned channel makes its connections has the exceptional width of $1\frac{1}{2}$ to 2 miles, and carries worn and receding bluffs that seem to be as old as the abandoned channel at its side. There is also some uncertainty as to the interpretation that this abandoned channel was opened by Eagle Creek. Its size is more in harmony with that of Big Bone Creek, and markedly less than the portion of Eagle Creek Valley with which it connects. At present it is uncertain whether by the abandonment of this valley the Eagle has been deflected from the Ohio to the Kentucky, or whether the Big Bone has been deflected from the Eagle-Kentucky drainage to the Ohio. This question is, however, of less importance to the subject under discussion than that of the existence of a gradation plain which corresponds quite closely with the remnants of gradation plains found on the lower course of the Licking and Kentucky.

Upon passing below Louisville to the portion of the Ohio outside the limits of glaciation, remnants of a gradation plain have been found on tributaries which enter through the resistant sandstone formation. They are especially well defined on Big Blue and Little Blue rivers, one of which enters above and the other below the abrupt bend made by the Ohio River at Leavenworth, Ind. Like the gradation plains of the Licking and Kentucky, they stand about 175 to 200 feet above the stream, but their altitude above tide is only about 550 feet, or fully 50 feet lower than the gradation plains near the mouth of the Kentucky. This is to be expected on the supposition that the drainage was along the present course. These gradation plains in the vicinity of Leavenworth stand about 150 feet below the level of the Tertiary deposits which, as above described, cap the bluffs of that portion of the Ohio Valley.

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[1] Bull. Denison Univ., Vol. XI, 1898, pp. 1–10.

In the 100 miles between the outcrop of the resistant conglomerate Coal Measures near Cannelton, Ind., and the point where the Ohio opens into the broad valley of the Lower Mississippi near Paducah, Ky., the rock formations are so friable that the bluffs are in large part broken down to a lower level than the gradation plains would be expected to occupy. It is scarcely possible, therefore, to carry a definite tracing of the gradation plains across this interval and connect them with the equivalent deposits on the Lower Mississippi. It is possible, however, that discriminative studies will make clear the equivalents on the Lower Mississippi both of the gradation plains and the Tertiary deposits of the Lower Ohio system.

DRAINAGE CHANGES NEAR CINCINNATI.

Reference has already been made to the old northward line of discharge of the Licking and part of the Ohio from Cincinnati, through the valley of Mill Creek, to the Great Miami near Hamilton, Ohio. The course of the Licking was through the western part of Cincinnati along the lower course of Mill Creek reversed, while that of the Ohio was around the east and north borders of the Walnut Hills upland to the junction with the old Licking in the north part of the city (see Pl. V). James, some years ago, made the interpretation that the course of drainage just outlined was continued from the Great Miami near Hamilton westward, through an abandoned valley, to the Whitewater River near Harrison, Ohio, and thence down the Whitewater Valley to its junction with the Great Miami Valley near the point where the latter joins the Ohio at Lawrenceburg, Ind.[1] The Ohio is thus given a detour of about 20 miles to the north of its present course. This interpretation has recently been in part called in question by Gerard Fowke,[2] who has suggested that the Ohio continued northward from Hamilton along the Great Miami Valley and that it received a tributary from the direction of Lawrenceburg instead of taking a course past that city.

While the course of drainage suggested by Fowke may have been operative at some remote period, as already indicated, it seems quite certain that the course suggested by James was in operation in the period of deep valley excavation that preceded the deposition of the oldest drift of that

[1] An ancient channel of the Ohio River at Cincinnati, by Joseph F. James: Jour. Cincinnati Soc. Nat. Hist., Vol. XI, 1888, pp. 96–104.

[2] Bull. Denison Univ., Vol. XI, 1898, pp. 1–10. Also Ohio Acad. Sci., Special Papers No. 3, 1900, pp. 68–75.

locality (the Illinoian drift). This abandoned course, unlike the abandoned course of the Middle Ohio from Wheelersburg to Waverly, was cut down before its abandonment to a level below that of the present Ohio. It corresponds apparently to the trenches or canyon valleys of the Middle and Upper Ohio systems. The rock floor of the valley being below the level of the present drainage lines, its slopes can be determined only by means of borings. From the data thus obtained along the abandoned course, as well as along the Ohio below the mouth of the Great Miami, it appears that the rock floor lies about 60 feet below the present low-water level of the Ohio, and has a descent in the present direction of drainage. From a level about 375 feet above tide at Cincinnati it falls to 360 feet or less at Rising Sun, Ind., and to 350 feet or less at the mouth of the Kentucky River. At Cincinnati the tests have been sufficiently numerous to show the full depth where the old Licking crossed the present Ohio. At other points the tests are not so numerous, but they are sufficient to show that the altitude of the rock floor becomes lower below the mouth of the Great Miami than it is at Cincinnati. Borings in the abandoned channel between Cincinnati and Hamilton show a rock floor as low as those in Cincinnati. So far as the writer is aware, no borings along the Great Miami above Hamilton have reached so low a level before entering rock as those on the Ohio below the mouth of the Great Miami.

In addition to the slope of the rock floor, there is the further evidence for the route suggested by James, in the presence of a broader valley along that line than on the Miami northward from Hamilton. The latter becomes reduced just above Hamilton to a width of less than a mile, and that, too, at a height of fully 200 feet above the level of the rock floor, and its general width as far up as Dayton is but little more than a mile. The abandoned valley leading west from Hamilton, in the route suggested by James, is 1½ to 2 miles in width, and there is no constricted place from there to the Ohio, nor down the Ohio to the mouth of the Kentucky. In this connection it may be remarked that constrictions farther down the Ohio near Madison, Ind., and Leavenworth, Ind., occur in the passage through escarpments of resistant rocks, where the valley has exceptionally high bluffs, and apparently do not lessen the size of the valley more than would naturally result from the greater resistance of the rock strata.

The earlier paper presented by Fowke is accompanied by a map which

aims to show that the tributary streams below the mouth of the Great Miami enter through valleys which point up the Ohio Valley. There are, however, streams which are omitted from that map, such as Gunpowder Creek and the North Fork of Big Bone Creek, which point very strongly down the Ohio Valley. It is also found that north from Hamilton tributaries of the Great Miami show a decided tendency to trend down the Miami Valley, not only at their points of entrance but throughout much of their course. This topographic feature, therefore, can scarcely be urged to sustain Fowke's interpretation.

From Cincinnati down to the mouth of the Great Miami the valley of the present river has scarcely half the width which it presents below the mouth of the Miami. Just below Cincinnati, where the stream is thought to have crossed an old divide (see Pl. V), the bluffs reach the exceptional height of about 450 feet, and are very abrupt nearly to the top. Upon passing down the valley they soon assume the worn and receding slopes characteristic of an old valley, though so much smaller than that opened by the Ohio past Hamilton that it seems the natural product of a stream draining only the tract between Cincinnati and the mouth of the Great Miami. If we may judge by the boldness of the bluffs, a prominent col was crossed in the vicinity of the supposed divide. There may, however, have been a narrow notch of considerable depth whose borders have been cut away by the present large stream.

The old divide crossed by the Ohio above the present mouth of the Licking River has been so greatly filled in by glacial deposits on the Ohio side of the river that its rock contours are much obscured. It is certain, however, that the bluffs are greatly degraded, and it is probable that a very low gap existed here at the time the deflection was produced.

RELATION OF THE GLACIAL DEPOSITS TO THE EROSION FEATURES OF THE OHIO VALLEY.

ON THE LOWER OHIO.

Before attempting to interpret further the changes of drainage which have resulted in forming the present Ohio River, it will be advantageous to consider briefly the relation of the glacial deposits to the erosion features. It so happens that the only part of the immediate valley of the Ohio which has been glaciated lies in the section called the old Lower Ohio, from

a point a few miles below Manchester, Ohio, down to the vicinity of Louisville, Ky. But along the entire length of the present valley assorted material derived from glacial deposits has been distributed, and much may be learned by determining the relation of this assorted material to the valley excavation.

The portion of the Ohio Valley which has experienced glaciation covers nearly the interval from Louisville up to Maysville, Ky., 190 miles, for the glaciation fell short but 5 to 10 miles of reaching the site of each of these cities. The abandoned course of the Ohio near Cincinnati should also be included, and as this is less direct than the present course it increases the length of the glaciated portion of the valley to about 225 miles. Throughout this glaciated portion, including the abandoned course of the stream, the drift deposits are found to extend down to a rock floor lower than the bed of the present river, and as these include till or unmodified glacial material it is evident that the excavation of the valley to its lowest depth preceded that stage of glaciation which produced these deposits. This particular glaciation, as explained farther on, belonged to the Illinoian stage. It is certain, therefore, that at that early stage this part of the Ohio was excavated to its full depth.

ON THE MIDDLE OHIO.

The Middle Ohio or old Kanawha system is less favorably situated than the Lower Ohio for determining the relation of the glacial deposits to the erosion features, for the part of the Ohio Valley which falls in that system was not reached by the ice sheet. It is also found that along the old northward outlet of that drainage system the Illinoian glaciation extended but a few miles beyond the later or Wisconsin glaciation. There are, however, a few features outside the glacial boundary which throw some light upon this question.

Above the level of the Wisconsin glacial terrace which leads down the Scioto to the Ohio there are deposits of gravel and sand derived apparently from Illinoian drift. Their height is 60 to 75 feet above the Wisconsin terrace, and they have been found along the Scioto for about 30 miles south from the glacial boundary or nearly to the Ohio River. They have been observed only on the remnants of the gradation plain of the small stream, which, as above described, seems to have been a southern or southwestern tributary of the old Kanawha, but the presence of glacial

pebbles makes it certain that they were deposited by water moving southward. There is additional evidence that these deposits were derived from the Illinoian drift in the fact that the glacial pebbles show more weathering than is commonly displayed by similar rocks found in the Wisconsin gravel. Although these Illinoian gravels have not been traced from the Scioto down the Ohio past the old divide, that course appears to have been the only available one for the stream which transported the gravel southward through the Scioto Valley. The gravels show a decided slope toward the Ohio from the glacial boundary. From an altitude about 700 feet above tide, at the point where the Scioto crosses the glacial boundary, just south of Chillicothe, their surface declines to about 650 feet near the mouth of the Scioto, 30 to 35 miles farther south. With the data now at command the writer is unable to make a definite estimate of the amount of trenching that had been accomplished in this part of the Ohio prior to the Illinoian stage of glaciation, but there was probably enough to give a downward slope from the mouth of the Scioto past the old divide near Manchester to the lower Ohio.

There are features in the region which indicate that the trenching of the gradation plain had extended up the Scioto beyond the glacial boundary before the close of the Glacial epoch, but it is not entirely certain that the trenching had been accomplished prior to the Illinoian glaciation. The features referred to are found in the valley of the South Fork of Salt Creek. This valley, and also the abandoned portion of the old Kanawha, in southern Ohio, was greatly filled by silt deposits, which are apparently of glacial derivation, for they are in a sandstone region and yet are quite calcareous. Borings in the vicinity of Jackson, 20 miles above the mouth of the stream, show that the silt deposits on South Salt Creek extend below the level of the postglacial valley excavation, and are 40 or 50 feet lower than the rock floor of the abandoned part of the old Kanawha west of Jackson, less than 10 miles distant. The correlative rock floor of this valley should stand a few feet higher than the rock floor of the old Kanawha, since it had its discharge into that valley. The fact that it stands so much lower is a clear indication that the valley had been deepened fully 50 feet between the reversal and partial abandonment of the old Kanawha and the deposition of the silt. That this amount of trenching occurred here on a small tributary of the Scioto is a matter of far more consequence than if it had been found along the present Ohio, in the vicinity of the old divide,

or even on the Scioto. The time required would seem adequate for the Ohio to cut down the old divide about to the level of the Lower Ohio, with which it connected, and for the Scioto to have extended its trenching from the present mouth northward into the Scioto Basin far beyond the mouth of Salt Creek.

Unfortunately there is an element of uncertainty as to the age of the silt which fills this trench. There is presumably a silt deposit in this valley which connects at the north with the Illinoian drift and perhaps silts of still earlier glacial stages. There was also in the Iowan stage of glaciation a widespread deposition of calcareous silt in this region, and the silts of the several stages have not been properly discriminated. If it can be shown that only the surface portion is of Iowan age and the deeper portion is Illinoian, the entire excavation would have occurred in pre-Illinoian time here, as well as in the Lower Ohio drainage system, and the two systems would probably have been connected at that early date about as at present.

ON THE UPPER OHIO.

It remains to consider the relation which the deposits that contain glacial material bear to the erosion features of the Upper Ohio. These deposits are of several classes and of different ages, and are found at all levels, from the rock floor under the river up to gradation plains which in one place attain an altitude nearly 400 feet above it. The deposits which occupy the valley bottom and rise to a height of 100 to 130 feet above the stream are generally referable to fluvial action during and subsequent to the Wisconsin stage of glaciation; but those which appear at greater heights are referable to earlier Pleistocene stages. At the Wisconsin stage the valley here as well as farther down appears to have been opened to its full depth.

A sheet of drift much older than the Wisconsin, and probably also older than the Illinoian, has furnished material for fluvial deposits which have been built up in the part of the Ohio Valley near the mouth of the Beaver to a height of about 980 feet above tide, or 100 feet above the main gradation plain, and 320 feet above the river. These deposits have as yet been found to cover the gradation plains of the old north-flowing system only as far as Toronto, Ohio, 35 miles below the mouth of the Beaver River. The surface of the gravel appears, from aneroid measurements, to descend in that distance 25 or 30 feet, being between 950 and 960 feet at Toronto.

Between Toronto and Moundsville there are occasional remnants of gravel deposits, containing glacial pebbles, on slopes and narrow rock shelves below the level of the gradation plains and above the Wisconsin gravel terrace, but the amount is small compared with that between Beaver and Toronto. There are also small amounts of glacial gravel at higher levels than the Wisconsin terrace south of the old divide, from Moundsville down nearly to Marietta. In that part of the valley they are found on the old gradation plain as well as on the slopes below it, but, as above noted, the altitude of the gradation plain south from the old divide is much lower than that of the best defined gradation plain of the north-flowing system.

The distribution of these deposits suggests that the valley at and above the old divide had been opened down about to the level of the gradation plain south of the divide prior to the culmination of the earliest glaciation, with its attendant deposition of the valley gravel.

This subject, however, should not be dismissed until attention has been called to certain features which seem difficult to harmonize with the view that considerable trenching across the old divide had occurred at the time of the first glaciation. On high rock shelves lying within the limits of the old north-flowing system south of Toronto there are scattering pebbles and thin deposits of loamy clay and fine sand. These deposits suggest a ponding of waters in the early stages of reversal, and there are suggestions of the presence of glacial material in the ponded waters. A deposit especially open to suspicion is a fine sand suitable for molders' use, which has been obtained on the rock shelves near Wheeling and Bellaire at about 1,000 feet above tide, but its glacial derivation has not as yet been demonstrated. In this connection attention is directed to a feature that seems somewhat inharmonious with this view. The pebbles found on these rock shelves are usually of resistant sandstone, probably of local derivation, and are deeply weathered; but on a rock shelf in the north part of Wheeling, standing 990 feet above tide, fresh-looking erratics were found. They are mainly small pebbles, an inch or less in diameter, of granite, greenstone, and quartzite. They are especially abundant in an open field south of the waterworks reservoir. Their fresh appearance, when in such an exposed situation, makes it seem doubtful if they were deposited by glacial waters at that high level. Possibly they have been brought up from a

terrace of Wisconsin age deep down in the valley, though upon inquiry no facts could be obtained to sustain this inference. From their general appearance they can scarcely be cited as evidence of the preservation of the old divide up to that altitude, but the molders' sand may prove to be a point in support of that view.

On the Ohio above the mouth of the Beaver, and also on the Lower Allegheny, glacial gravel has been found on the gradation plain all the way up to the supposed divide near the mouth of the Clarion, which is near the point where the Allegheny passes from the glaciated into the unglaciated region. It covers the gradation plain to a depth of 40 to 100 feet, the greatest filling being near the mouth of the Beaver, where the old drainage turned away from the present Ohio.

The amount of trenching which this part of the old Upper Ohio had suffered before the deposition of the earliest glacial material is a matter which has been in controversy for some years. On the slopes of the trench which has been cut in the old gradation plain there are patches or thin sheets of glacial gravel which have afforded grounds for different interpretations, it being maintained by some that they demonstrate the preexistence of a trench at the time of the earliest filling with glacial material, while it has been held by others, among whom the writer is included, that they represent probably the incidents of degradation subsequent to the earliest filling. The following are the grounds set forth some years ago by Chamberlin and Leverett for doubting the preexistence of a deep trench:[1]

> Between the base of the undisputed high-level gravels and the summit of the low-level systems, gravel is found at numerous points on the sides of the Allegheny trench. This gravel is commonly found on sloping points in the inner bends of the river and in other localities where, in cutting down its valley, the river would be likely to leave remnants of gravels, if they were there before, or would permit their lodgment in the process of sinking its bed, if not there before. Herein lies the radical difficulty of their interpretation. A winding stream, which is cutting down its bed at a moderate rate, tends to extend its meanders as well as deepen its floor, and so it cuts outward as well as downward on the convexities of its bed and is disposed to permit the lodgment of material on its concave side, where the tendency of the stream is to recede. Now, the Allegheny, during the whole process of its descent from the level of the high terraces to its present position, was undoubtedly a gravel-bearing stream. It was not only engaged in the process of removal of the gravel along its own immediate course, but was receiving very much that was washed in from the drift region adjacent, so that a certain amount of lodgment of transported

[1] Am. Jour. Sci., 3d series, Vol. XLVII, 1894, pp. 275–277.

material may be assumed to have been inevitable. This is dependent upon the same principle of action that would permit the retention of gravels in such situations if they had been previously deposited within the trench.

As the gravels on the slopes are usually thin sheets or patches, we have not found decisive evidence, in themselves, as to whether they are remnants of earlier gravels, or incidents of degradation. We have searched industriously for evidence that should be decisive on this point. Such evidence should be found in abandoned segments of the old valley, if it had been deeply excavated before the deposit of the gravels and had subsequently been filled by these up to the summit of high gravels. These high gravels fill oxbows and recessed shelves, and the stream which deposited them had, in many instances, alternative courses. This is notably true in the vicinity of Pittsburg. Here the old high plain of rock was extensively covered by the waters that deposited the gravels, as is shown by the presence of remnants. There are, in the eastern part of the city, four islands surrounded by broad channel ways, among which the waters distributed glacial gravels in greater or less degree. Now, if the present deep Allegheny and Monongahela trenches had been cut previously to the filling in of the gravels, there is only a small chance that, after the gravel-depositing period, during which they were flowing 50 feet or more above the rock plain, they would have descended the second time on precisely the same lines. Between the several broad channels open to them the possible combinations are 32 in number, and hence theoretically the chances of a combination repeating itself are one in 32. If it be objected that certain of the courses are more favorably situated than others, our answer is, first, why were these others then ever produced by the streams or occupied by glacial wash; and our second answer is, that if this be true of certain combinations, it does not seem to us to be at all true of many others.

Besides this, along the Allegheny River above, and also along the Ohio River between Pittsburg and Toronto, to which point the high gravels containing Canadian pebbles have been traced, there are perhaps a score of oxbows, deep recesses, shelves, or available cols which would afford opportunities for the redescending river to locate itself on other lines than its old track with all its meanders. When these possibilities are added to the preceding it becomes exceedingly strange that, below the mouth of the Clarion, no abandoned channel is found which retains any old filling comparable in depth to the present trench. We find numerous channels containing gravels ranging from 50 to a little over 100 feet that represent such old courses on the higher plain. This demonstrates the truthfulness of the principle here urged, and shows its application to this particular field.

The hypothesis that the river trenches of this region had been cut to essentially their present depth before the earliest glaciation encounters another serious difficulty in that it calls for a greater amount of valley filling than can well be postulated. It necessitates enough valley gravel during that glaciation to produce a filling fully 300 feet in depth for a distance of at least 250 miles, and that, too, while the ice edge occupied the narrow belt between the glacial boundary and the basin of Lake Erie. The amount of material

required to spread a deposit 40 to 100 feet in depth over the surface of the gradation plain seems surprisingly great when the limited extent of glaciated country tributary to this drainage system is considered, but this must be doubled or trebled to fill the trenches. It would be far in excess of the outwash from the Wisconsin, for that has been sufficient to fill the trench to an average depth but little more than 100 feet, and it had the advantage of contributions from the earlier gravel deposits all along the line.

It should not be inferred that the gradation plains of the Upper Ohio region had reached only an incipient state of trenching down to the time when those of the Middle and Lower Ohio had suffered trenching to their full depth. The glacial deposits of the Upper Ohio region apparently belong to a stage of glaciation much earlier than that which furnished the drift of the Lower Ohio region. The latter is of Illinoian age, while the former, as indicated below, seems to be fully as old as the Kansan drift, if not of pre-Kansan age. A sufficient amount of valley trenching may have occurred in the Upper Ohio region between the earliest glaciation and the Illinoian stage to bring it into harmony with that of the Lower Ohio system. The precise amount of trenching can scarcely be estimated in the present stage of investigation.

ALLEGHENY RIVER.

The Allegheny River, the main headwater tributary of the Ohio, drains an area of about 11,500 square miles, 2,000 square miles being in southwestern New York, and 9,500 in northwestern Pennsylvania. The river rises in Potter County, Pa., near the sources of the Genesee and the Susquehanna, and runs northwestward into southwestern New York. It there turns southwestward and holds this general course to its mouth at Pittsburg. The length of the valley is about 325 miles. The length of the stream is but little more, for throughout much of its course its meanders conform to the windings of the valley. In the headwater portion, for about 160 miles, the curves are less sharp than in the lower portion of the valley, though the course is far from direct. In the lower portion the valley makes several sharp oxbow loops, in some instances nearly severing the prominent ridges inclosed by them.

RATE OF FALL.

The source of the river is near the crest of the Allegheny Mountains, in passes which stand about 2,200 feet above tide. The highest ridges in

that vicinity exceed 2,500 feet. In the first 20 miles, to Coudersport, Pa., the fall is very rapid, but below this point the valley has been silted up and the rate of fall becomes very much reduced. In the 30 miles from Port Allegany, Pa., to Olean, N. Y., the fall is only about 50 feet, or less than 2 feet per mile, and this low rate continues to Salamanca, 20 miles below Olean. The following condensed statement of the fall of the river from Olean to Pittsburg is taken from Roberts's Report on the Survey of the Allegheny River.[1]

Fall of Allegheny River from Olean, N. Y., to Pittsburg, Pa.

	Feet per mile.
First 20 miles below Olean	1.7
Second 20 miles	3.7
Third 20 miles	5.0
Fourth 20 miles	3.5
Fifth 20 miles	3.5
Thirty-two miles to Franklin	3.0
Franklin to Pittsburg, 123 miles	2.1
Average Olean to Pittsburg, 255 miles	2.8
Average Olean to Franklin, 132 miles	3.4

From the same report it appears that there are 190 riffles between Olean and Franklin, with an average length of 617 feet and an average descent of 1.6 feet. These riffles have a combined length of 22.2 miles and an aggregate descent of 304.77 feet. This leaves 141.49 feet descent for the 110 miles not occupied by riffles, or a descent of less than 1.3 feet per mile. From an earlier report by Roberts[2] it appears that between Franklin and the mouth of Conemaugh River, 30 miles above Pittsburg, there are 58 riffles, with an average length of 1,460 feet and an average descent of 2.46 feet. There are 11 riffles in the lower 30 miles of the river, but their length and descent have not been ascertained.

The most formidable riffle in the entire length of the portion surveyed is "McGinnis Rapids," about 8 miles above the mouth of the Clarion River, where a descent of 11.23 feet is made in a distance of 6,900 feet. This is described to be a connected series of rapids, shoalest at the head. About one-half mile above the head of the rapids the river has a rock bed, but it is not certain that the rapids are over rock ledges; nor is it certain that the rock ledge over which the river flows extends entirely across the valley at a level as high as the river bed.

[1] Senate Doc. No. 89, Forty-sixth Congress, second session, 25 pages.
[2] House Doc. No. 21, Forty-fifth Congress, third session, 17 pages.

In this connection it may be remarked that the river has a rock bed at but few places in its entire length, and the rock floor lies usually 20 to 50 feet below the stream. In the headwater portion, as indicated below, it lies at a great depth below the stream; yet in that portion a rock ledge is crossed by the stream at Limestone Falls, about 7 miles above the point where the river returns from New York into Pennsylvania, and a fall of 3.84 feet occurs in a distance of 650 feet.[1] The stream there is near the left bluff, and a buried channel is to be expected in the middle of the valley that will extend perhaps 200 feet below river level.

ROCK FLOOR.

In the upper 20 miles of its course the rock floor is but little below stream level, but in the next 20 miles it becomes covered to a depth of about 200 feet, while at Olean, and for nearly 30 miles below that city to Cold Spring Creek, it is covered to a depth of fully 300 feet. From the mouth of Cold Spring Creek, near Steamburg, N. Y., the Upper Allegheny, as indicated by Carll, formerly led away from its present course to enter the Lake Erie Basin.[2]

Down the present Allegheny from Cold Spring Creek the rock floor shows a rise of about 150 feet in the 25 miles to Great Bend, Pa., 8 miles above Warren, where the old divide pointed out by Carll has been crossed. It drops about 70 feet in the 8 miles to Warren, below which, for 10 miles or more, it appears to hold a nearly uniform level about 1,100 feet above tide. A descent then begins, which apparently continues the entire 175 miles to the mouth of the stream, at a level 20 to 50 feet below low-water level. In this lower end of the valley, therefore, it resembles the rock floor of the Ohio, but in the upper part its relation to the present stream is different. Although the rock floor in the lower end of the valley shows a descent with the present stream, it does not follow that there has been no change of drainage. Here, as on the Ohio, the old divides have been cut down below the level of the stream sufficiently to give a gradient in harmony with it. But in the upper part of the Allegheny the old streams flowed in plains so far below the level of the present river that their rock floors have not been touched by it.

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[1] Roberts's Report, Senate Doc. 89, Forty-sixth Congress, second session, pp. 13 and 23.

[2] Second Geol. Survey Pennsylvania, Rept. I[3], 1880, pp. 333–355.

DESCRIPTION OF THE VALLEY.

At the source of the Allegheny the dividing ridges between the Allegheny, Genesee, and Susquehanna rivers have an altitude of 2,500 to 2,600 feet. Down the Allegheny the highest points on bordering uplands fall to about 2,500 feet near Port Allegany, to 2,425 feet near Olean, to 2,375 feet near Salamanca, and to perhaps 2,200 feet in the vicinity of Steamburg, where the present channel departs from the old one. There is a slight rise southward from that point to the old divide near Kinzua, Pa., the uplands reaching an altitude of 2,150 feet on the immediate borders of the valley west of Kinzua. From this point there is a general descent toward the mouth of the present river, the altitude near Warren being about 1,950 feet, near Tidioute 1,750 feet, near the mouth of the Clarion River 1,550 feet, and near Pittsburg 1,200 to 1,300 feet. A comparison of these altitudes with the altitudes of the stream shows that the stream flows at a level 500 to 800 feet or more below the highest parts of the bordering uplands, while the rock floor in the deeply filled portions in northern Pennsylvania and southwestern New York was cut 1,000 to 1,100 feet below the bordering uplands. The course of the stream, as may be seen by reference to the glacial map (Pl. II), lies within a few miles of the glacial boundary, a large part being just outside the limits of the drift and none of the valley far inside the drift border.

The Allegheny Valley increases gradually in width in the northwest portion from its source to the point where the present stream departs from the old course near Steamburg, N. Y., the width being one-fourth to one-half mile from Coudersport to Port Allegany, and one-half to three-fourths mile from Port Allegany to the bend just above Olean, N. Y., below which, as far as Cold Spring Creek, the width is a mile or more.

Southward from the mouth of Cold Spring Creek the valley maintains a width of a mile only as far as the vicinity of the State line. From Corydon to Kinzua, Pa., it has a width of scarcely three-fourths of a mile. At the old divide below Kinzua it narrows abruptly to a width of but one-fourth mile, and remains narrow nearly to the mouth of Conewango River at Warren. It there expands to a width of about a mile, and maintains this width from Warren to the bend near Irvineton, a distance of 8 miles. Upon passing south from Irvineton it soon decreases to less than one-half mile, being much narrower than the valley of Brokenstraw Creek,

which enters the Allegheny at Irvineton. It continues narrow as far as the mouth of the Clarion River, being in places scarcely one-fourth mile, and rarely exceeding one-half mile, in width. In this narrow portion there are occasional remnants of the fluvial plain of the small predecessor of the middle portion of the Allegheny, which, as indicated below, discharged northwestward along French Creek (reversed), and eventually reached the Lake Erie Basin.

At the mouth of Clarion River a broad gradation plain comes in from that valley and continues down the Allegheny to its mouth. This has been trenched to a depth of about 200 feet below the level of the old rock floor. The trench or inner valley is usually about one-half mile in width, though it increases to nearly a mile near the mouth of the stream. At the level of the gradation plain there is a general width of about 1 mile. This gradation plain is capped by a deposit of sand and gravel, with an average thickness of perhaps 40 feet, that serves to accentuate the terrace-like appearance, for it fills up small trenches that had been cut in the gradation plain prior to the gravel filling. It is scarcely necessary to state that above the level of this gradation plain the bluffs are far more worn and receding than in the inner or canyon valley lying below it.

OLD UPPER ALLEGHENY DRAINAGE SYSTEM.

Evidence that the upper portion of the Allegheny drainage basin formerly discharged northwestward to the Lake Erie Basin was presented by Carll some twenty years ago.[1] He called attention to the constriction of the present valley near Kinzua, Pa., and noted that the rock floor of the valley slopes northward or in the reverse direction from the present stream from this point to the mouth of Cold Spring Creek, where it is met by a a rock floor sloping with the present stream. He also noted a broad valley deeply filled with drift leading westward from the mouth of Cold Spring Creek to the headwater portion of Conewango Creek. Having no opportunity to examine the divide at the head of Conewango Creek, he suggested an outlet to the Lake Erie Basin along the rather broad valley of Cassadaga Creek, a tributary of the Conewango. In this suggestion he seems to have been in error, for a much broader valley leads northward across the low divide between Conewango and Cattaraugus creeks, and

[1] Second Geol. Survey Pennsylvania, Rept. I^3, 1880, pp. 1–10, 330–439.

thence down Cattaraugus Creek to the lake. In favor of the route across the divide between Conewango and Cattaraugus creeks there is not only the greater width of the valley, but also its more direct course to the lake basin and the presence of a channel deeper than is known to be present in the Cassadaga Valley. Three wells along it penetrate drift to depths of 284, 314, and 330 feet, respectively, without reaching rock, while a fourth, in Cattaraugus Valley, at the Indian Asylum near Versailles, penetrated about 200 feet of drift.

The northward slope of the rock floor and its wide departure from the bed of the present streams is in part shown diagramatically in fig. 4. On a subsequent page it is shown that on this line, as well as on other ancient drainage lines of this region, the northward slope of the rock floor may be somewhat modified by surface warping. There may also have been consider-

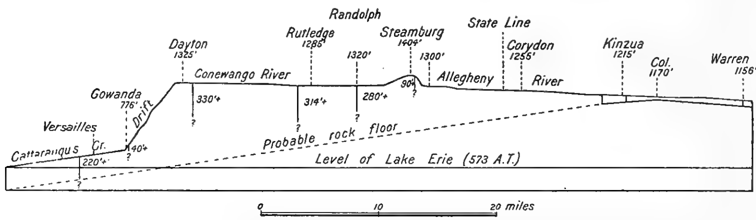

FIG. 4.—Diagram to show the relation between the present stream bed and the old rock floor along the preglacial Upper Allegheny River. The numerals above the stream bed indicate surface altitudes, while those below show the depth to which wells have penetrated. The sign (?) indicates that rock was not reached.

able rock excavation by an interglacial stream along this line in the vicinity of the lake basin, it being not improbable that an interglacial stream would have had its source somewhat south of the present divide, which is a moraine of Wisconsin or late glacial age. Both factors need to be eliminated in determining the rate of slope of the rock floor of preglacial times. The present rate seems too great for the nature of the valley. It may also be necessary to make allowance for excavation by ice or by currents of water underneath the ice in the portion of the valley within the glacial boundary, but such an excavation could not have occurred in the portion of the valley with northward-sloping floor which lies outside the glacial boundary, i. e., between Kinzua and Cold Spring Creek.

The general configuration of the drainage features of the region support this view of reversal or change in drainage, as may be seen by refer-

ence to the map of the restored drainage (fig. 1, p. 89). The naturalness of this restored system lends support to the more positive evidence just cited.

It should be noted that the old divide between the small streams which flowed south into the Upper Allegheny and those which flowed north into Cattaraugus Creek was farther south than the present divide. Above the village of Ischua the headwater portion of Ischua Creek appears to have discharged northward past Machias to Cattaraugus Creek. The changes on the headwaters of other tributaries are of less consequence. Cattaraugus Creek departs somewhat from the ancient line of drainage, as noted in the discussion of that stream.

It is somewhat difficult to decide upon the extent of the basin drained by the western tributaries of the old Upper Allegheny, for the valleys and lowland tracts have been so greatly filled by glacial deposits that the old divides are concealed. Probably much of the drainage areas of Cassadaga Creek, Chautauqua Lake, and the lower portion of Conewango Creek were tributary to the Upper Allegheny along the valley leading from Jamestown eastward to Randolph, N. Y.

It is possible that the Conewango Valley was a line of northward discharge for a small section of the present Allegheny between the old divide near Kinzua and a divide near Thompson station, about 12 miles below Warren, Pa., and also for the part of the Tionesta drainage basin above Barnesville, Pa. It is certain that the upper portion of the Tionesta discharged northward through Glade Run to the present Allegheny at Warren, as pointed out by Carll. The old divide where reversal took place is readily located near Barnesville, where, as noted by Carll, the stream enters a narrow gorge scarcely one-fifth the width of the abandoned channel. It also seems evident, from a constriction of the Allegheny Valley that sets in near Thompson and from other features discussed below, that the discharge could not have been down the present Allegheny. The only element of uncertainty is the course of the drainage—whether it was northward through the Conewango reversed, or westward through the lower course of Brokenstraw Creek and a deeply filled broad valley connecting Brokenstraw Creek with Oil Creek along the line of the Dunkirk, Allegheny Valley and Pittsburg Railway. The rock floor in the lower course of Conewango Creek and on the Allegheny between Warren and the mouth of Brokenstraw Creek is shown by numerous oil borings to be nearly level,

while on the old line of northward drainage for the Tionesta and on the portion of the Conewango north from Russellburg, Pa., the rock floor shows a perceptible northward slant. This singular feature may perhaps be due to a recession of the Thompson col through valley excavation, as suggested by Carll,[1] and the formation of a pseudo-col north of Warren at a point where excavation and recession were interrupted by a later filling with glacial gravel.

The valley leading westward from the lower course of Brokenstraw Creek into the Oil Creek Basin has been insufficiently tested by borings to furnish satisfactory evidence concerning the slope of its rock floor or the altitude of the floor compared with that of the Lower Conewango. A decision between these two routes can scarcely be rendered until a better knowledge of the western line is obtained.

OLD MIDDLE ALLEGHENY DRAINAGE SYSTEM.

This basin includes the lower portion of the Tionesta (below Barnesville post-office), the Allegheny from the old col at Thompson's to near the mouth of the Clarion, and the tributaries of this part of the Allegheny, except the headwaters of Oil and French creeks, as indicated in fig. 6. Several lines of evidence unite in indicating that this district formerly discharged northwestward along or near the lower course of French Creek nearly to Meadville and thence past Conneaut Lake to Conneaut Creek and the Lake Erie Basin. Evidence in favor of the reversal in the part below the mouth of French Creek is found in the narrowness of the Allegheny Valley above the mouth of the Clarion, as compared with the Clarion-Lower Allegheny Valley. Evidence is also found in an elevated tract which is crossed by the Allegheny immediately above the mouth of the Clarion, and in the rock shelves or old rock floors of the Allegheny and French Creek valleys.

Attention has already been called (p. 129) to the broad gradation plain, a mile or more in average width, which follows the Lower Allegheny at a level about 200 feet above the present stream, and to the fact that this gradation plain follows up the Clarion, but does not extend up the Allegheny above the mouth of the Clarion, for that part of the Allegheny has a narrow valley with precipitous bluffs reaching a height of nearly 400 feet above the stream.

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[1] Second Geol. Survey Pennsylvania, Rept. I^4, 1883, p. 311.

The force of this evidence has also been noted in showing either that a disproportionately small gradation plain with high cliff borders lay in this narrow gorge (having a breadth of only one-third to one-half that of the Clarion and Lower Allegheny gradation plain) or that there has been a reversal of drainage by which a small stream that formerly flowed northwestward through this gorge to join the French Creek–Conneaut outlet was reversed and its valley recut to fit the new and larger stream. The balance of probabilities in favor of the latter has also been set forth.

There seems to be evidence that the portion of the present Allegheny between the supposed col near the mouth of the Clarion and the French Creek outlet has been derived from parts of two valleys, each discharging northwestward, but separated by a divide below the mouth of East Sandy Creek. This view is supported not only by a notable constriction there (to a width of scarcely 1,000 feet) but also by an abandoned valley leading northward from the bend of West Sandy Creek at Polk (Waterloo) to French Creek Valley, just above the mouth of Sugar Creek, which would afford a northward outlet for the western stream. The relationships of the present streams to this abandoned valley and to the supposed col may be seen by a comparison of figs. 5 and 6. This comparison will also serve to show how natural is the restored system compared with the disturbed and unnatural present system.

Turning next to the line of evidence found in the rock shelves and terraces, a general inspection of the French Creek Valley shows that there has been broader and deeper excavation than on the Middle Allegheny. But inasmuch as the French Creek Valley lies within the glacial boundary, and its lower course nearly coincides with the direction of the ice flow, it seemed necessary to determine whether its greater size may not be due in the main to glacial excavation. An examination of the valley with this question in mind led to the discovery of old channels and ox-bow curves of preglacial streams whose preservation is so complete as to furnish decisive evidence that glacial excavation has been of little consequence in causing the size of the southern end of the valley.

Along the valley which led past Waterloo from the highland tract near the mouth of the Clarion to the present French Creek Valley there are remnants of an old valley floor near the supposed divide at an altitude of 375–400 feet above the river, or 1,275 to 1,300 above tide, while at Waterloo,

in the abandoned valley which leads from Sandy Creek northward to French Creek, the rock floor is shown by several oil wells to have an altitude about 1,050 feet above tide. This valley is filled with drift apparently of early glacial age, and its rock floor has not suffered excavation since the drift deposition. Its rock floor is the probable continuation of the elevated rock floor of the headwaters and indicates a descent of somewhat more than 200 feet in 18 to 20 miles. This rate of fall would be natural in such a small stream descending from the elevated table-land, and differs but little from the rate of fall in southern tributaries of the upper Allegheny of corresponding size—e. g., the fall on the Tuna, a similar stream, from De Golia, Pa., to the mouth of the stream, a distance of 14 miles, is 215 feet.[1] At the north end of the abandoned valley, where it opens into French Creek, a rock floor is struck in wells at an altitude about 975 feet above tide, which seems to mark the continuation of the old valley floor.

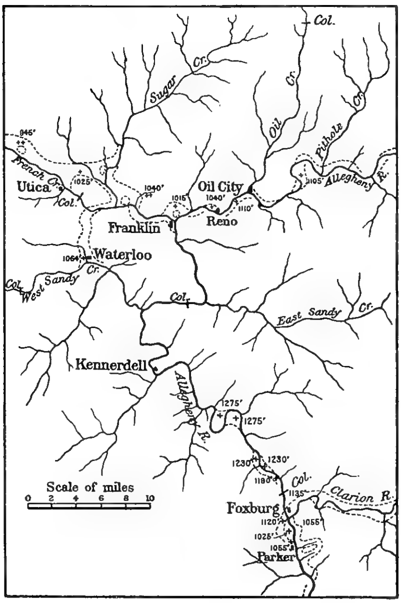


FIG. 5.—Present drainage of part of the Middle Allegheny drainage system.

Turning now to the main stream of the old Middle Allegheny, it appears probable that the col at Thompson's had a height of at least 1,220 feet. At Tidioute, 8 miles below, early glacial gravels rest on a rock shelf that represents the old river bottom at 1,160 feet above tide. At Reno a similar shelf stands only 1,040 feet; while at Franklin, in an oxbow filled with early glacial gravel (see Pl. VIII), one boring reached rock at 1,040 feet above tide, and another penetrated to a level only 1,015 feet above tide without reaching rock. The gravel at these points rises to a level much above that of the terraces connected with the outer moraine of the Wisconsin or late ice inva-

[1] See Carll: Second Geol. Survey Pennsylvania, Rept. I[3], p. 334.

sion, and sustains such relations as to show clearly that it has suffered no disturbance since deposition. The shelves, therefore, antedate the gravel, and are remnants of an old river bottom. The hill standing between the old channel and the present river (see Pl. VIII) seems to have been detached from the bluff south of the river. This change was probably brought about at the time the valley became filled greatly with glacial gravel, the amount of filling being sufficient to raise the stream above the level of the old neck that joined the hill to the south bluff.

Following the supposed outlet northwestward, there is an old meandering valley lying near the present French Creek and in part coinciding with it (see fig. 5). On a small eastern tributary of this old valley 3 miles northwest of Franklin, wells situated a mile or more back from the junction of the tributary with the old valley strike a rock floor at about 1,040 feet above tide, which is about as low a level as the rock floor found in one of the wells in the Franklin oxbow, and is within 25 feet of the bottom of the other. These wells penetrate about 100 feet of drift of early glacial age. As they are back from the principal valley, the presumption is that the main channel is lower. Farther northwest along the valley, at a point 8 miles from the Allegheny, a well is found which reaches the rock floor at 1,025 feet above tide—i. e., at a depth intermediate between the depths of the two wells in the abandoned oxbow at Franklin. This well is situated near the southern edge of the valley and can scarcely be supposed to have struck its deepest portion. Again, in an old oxbow 3 miles north of Utica, similar in every way to the oxbow at Franklin except that it lies within the limits of the Wisconsin ice invasion, the floor is shown by

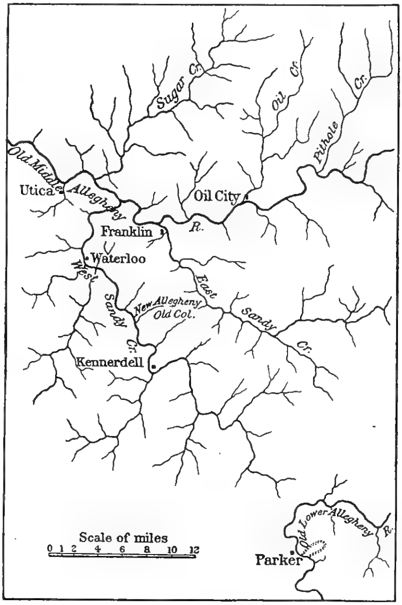
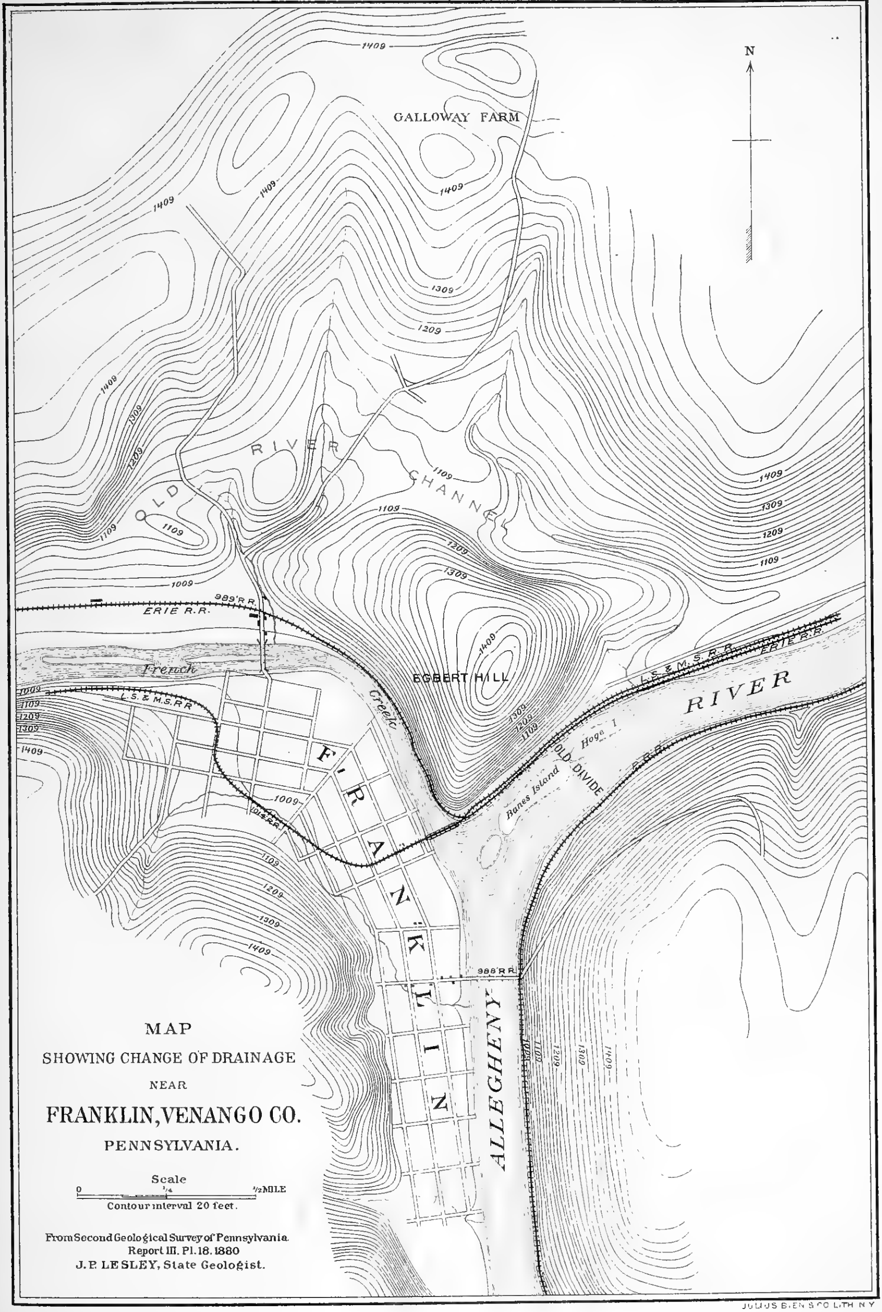


FIG. 6.—Probable preglacial drainage of part of the Middle Allegheny drainage basin.

one well to be 945 feet and by another 960 feet above tide—i. e., 70 feet and 55 feet, respectively, below the bottom of the lowest well in the Franklin oxbow. Still farther northwest, on French Creek, at Cochranton, Buchanan, and Meadville, there are wells showing excavation to even greater depths; the first two not reaching the bottom at 915 and 800 feet above tide, respectively, and the last finding rock at 605 feet above tide. The depth of drift at this last point is reported to be 475 feet, and the rock bottom is only 32 feet above Lake Erie. The low altitude at Meadville seems to be confined to a narrow trench, for within short distances either side the rock floor is 100 to 200 feet higher. The conditions here are somewhat problematical, as in the north end of the old Upper Allegheny.

The evidence seems very strong that the oxbow at Franklin, the old channel northeast of Utica, and the oxbow north of Utica are remnants of the floor of the same old meandering stream leading northwestward. The fact that the rock floor in the oxbow north of Utica is 70 feet below the deepest determination of the old channel where it left the present Allegheny renders it highly improbable, if not impossible, that it was formed by a stream discharging toward the Allegheny. It is even lower than the present rock bottom of the Allegheny, notwithstanding all the erosion the latter is believed to have suffered since the deposition of the early glacial gravels. It is highly probable, therefore, that we have in these abandoned valleys a continuation of the old Middle Allegheny. An inspection of the general configuration of the old channel, as shown in fig. 6, will add to the force of these considerations.

An objection to the northwestward outlet may perhaps seem to be presented by deposits of gravel which occur along the Allegheny Valley between the mouth of French Creek and the mouth of the Clarion. In several places, notably at the bends of the river at Brandon, at a point 2 miles below Brandon, at Kennerdell, at Black's (Winter Hill station), and at Emlenton, there are deposits on the face of the gorge extending from near the river's edge up to heights of 200 to 300 feet or more above the stream. The occurrence of this gravel at low levels can not be accounted for by creeping or landslides, since in some places, notably at Kennerdell and 2 miles below Brandon, the gravels show clearly by their situation and bedding that they have not been disturbed since the stream deposited them. We are not, however, reduced to the one interpretation that the valley had



MAP
SHOWING CHANGE OF DRAINAGE
NEAR
FRANKLIN, VENANGO CO.
PENNSYLVANIA.

Scale
0 1/4 1/2 MILE
Contour interval 20 feet.

From Second Geological Survey of Pennsylvania
Report III. Pl. 18. 1880
J. P. LESLEY, State Geologist.

JULIUS BIEN & CO. LITH. N.Y.

been opened to its present depth and had southward drainage before the beginning of the glacial period. These gravels are in every observed case situated on sloping points on the inner curves of sharp bends in the river. At such places a stream works outward as well as downward, there being erosion on the outer curve and liability of deposition on the inner curve. It is to be expected, therefore, on the hypothesis that the stream has greatly deepened its channel since the ice invasion, that such deposits should be present, and these deposits do not, it is thought, necessarily oppose the hypothesis of former northwestward drainage, nor that of great erosion since the beginning of the Glacial epoch.

Concerning the line of discharge for the Middle Allegheny from near Meadville to the Lake Erie Basin a few remarks seem necessary. It is certain that the old drainage line did not follow French Creek Valley northward beyond Meadville, for there is clear evidence of an old divide on the present creek a short distance above that city. The line described by Carll as the Conneaut outlet departed from French Creek about 4 miles below Meadville, followed up the outlet of Conneaut Lake to that body of water, passed northward across a low divide filled heavily with drift to the northward-flowing portion of Conneaut Creek, passed down that creek to the bend near Albion, then continued northward and entered the Lake Erie Basin a few miles east of the Ohio-Pennsylvania line.

Another valley-like lowland leads from Meadville along Cussewago Creek (reversed) nearly to its source, and thence northwestward to the Conneaut outlet near Albion, through a region heavily covered with drift. The Cussewago channel is narrower than the Conneaut and seems, on the whole, a less probable line of discharge for the Middle Allegheny. The northern end, however, afforded a line of discharge for a portion of the French Creek valley above Meadville, as indicated on page 139.

On both the Conneaut and Cussewago channels the borings are too few to afford a satisfactory knowledge of the rock floor. At the border of Lake Erie, for several miles each side of the place where the old stream entered, the rock surface seldom rises above lake level. It is probable that the channel of the old stream had reached a level in harmony with the bed of the lake.

It was suggested by Carll[1] that the headwater portion of the Shenango

[1] Second Geol. Survey Pennsylvania, Rept. I^3, pp. 5–6.

connected with the Conneaut outlet along the line of the old Beaver canal. In apparent support of this view, there is found to be a very low divide on this line composed of drift. But within a short distance back from the canal on either side rock appears above the canal level, a feature which suggests that the drift here covers a low rock ridge instead of an old channel. It seems probable, therefore, that the middle Allegheny received very little of the present Shenango drainage.

OLD DRAINAGE BETWEEN THE UPPER AND MIDDLE ALLEGHENY DRAINAGE SYSTEMS.

The greater part of Brokenstraw, Little Brokenstraw, Oil, and French Creek drainage basins appear to have been largely independent of either the Upper or Middle Allegheny. Instead of discharging, as now, in a southeastward direction to the Allegheny, they appear to have taken a northwestward course to the Lake Erie Basin. Only a small part of the ancient drainage can be readily traced, owing to the deep filling of drift, which completely conceals many of the low divides and renders it difficult, if not impracticable, to locate them. The borings, also, are not sufficiently numerous to afford a satisfactory knowledge of the slope of the rock floors, except in a few localities especially favored by oil-well borings. The present discussion can therefore set forth only a few of the points which bear upon the ancient courses of drainage.

The enlargement of Oil Creek, a small northern tributary of the Middle Allegheny, was brought to notice by Carll.[1] He called attention to the old divide just south of Titusville, and to the fact that in the part of the present creek above this divide the rock floor slopes toward the Lake Erie Basin.

The region now drained by French Creek seems to have suffered greater changes than that drained by Oil Creek. Indeed, the present stream appears to unite several areas which were drained by distinct lines. The lower course, as already indicated, formed the old line of discharge for the Middle Allegheny, while a small section in the middle of the present valley was occupied by the stream which drained the headwater part of the present Oil Creek Basin, and which may be called Muddy Creek, from the stream which now connects it with the Allegheny. Between these two lines of drainage there was a smaller line which crossed the present French

[1] Op. cit., pp. 356–360.

Creek Valley at Saegerstown, which may, perhaps, be denominated the old Woodcock Creek, since a stream by that name now drains the headwater portion of the valley, entering French Creek at Saegerstown. French Creek crosses another old divide in the extreme southwest corner of New York. The drainage systems thus united may never have been entirely distinct, but they certainly have been greatly modified in their courses and connections.

The old Woodcock Creek passed directly across French Creek through a depression, now deeply filled with drift, which leads past Mosiertown to Cussewago Creek, from which it apparently continued northwestward near Crossingville and Pleasant Valley to the old Middle Allegheny or "Conneaut outlet" in the vicinity of Albion, Pa. At the point where the old stream crosses French Creek the width is nearly one-half mile, or about double that of the present valley of French Creek just above and below the line of this old valley. Although this ancient line drained an area much smaller than the present French Creek, its age was so many times greater than that of these new portions of the creek that the amount of excavation is greater. Wells at Saegerstown enter rock at only 30 feet below French Creek, or about 1,070 feet above tide, but it is probable that the deepest part of the old valley has not been struck by them. These wells, however, stand in the midst of French Creek Valley, and bear strong testimony to the absence of a deep channel between Saegerstown and Meadville. The old divide crossed by French Creek on each side of the old Woodcock Creek apparently stood but 50 to 60 feet above the present creek; at least the rock rises no higher than that on the immediate borders of the stream.

No difficulty was experienced by Carll in tracing the old upper part of the Oil Creek drainage northwestward to French Creek through the broad lowland now occupied by Muddy Creek; but the line of discharge from French Creek to the Lake Erie Basin was not so readily determined. There appear to be rock barriers on the line of the two principal lowlands leading from French Creek toward the basin, one of which is drained by Le Bœuf Creek and the other by Conneautee Creek. On account of these apparent barriers the old line of drainage was thought by Carll to have followed down the present course of French Creek to the Conneaut outlet near Meadville. In giving the stream this route he apparently overlooked

the two old divides just noted, one of which is crossed by French Creek between Cambridge and Saegerstown, and the other between Saegerstown and Meadville. The presence of these old divides makes it necessary to give the stream a different course from Cambridge to the lake. The great amount of drift in the region through which it must have passed has nearly, if not quite, concealed the line of discharge, hence it is not possible at present to trace the line through to the lake.

As indicated in the discussion of the Upper Allegheny, there is a possibility that a small section of the Allegheny, together with the headwater portion of Tionesta Creek and the lower course of Conewango Creek, formerly discharged southwestward into the upper part of Oil Creek drainage basin past Grand Valley, carrying with it the lower courses of Brokenstraw and Little Brokenstraw creeks, as well as several smaller streams now tributary to the Allegheny. This being the case, a much larger stream than the present headwater portion of Oil Creek (above Titusville) discharged through Muddy Creek channel. It seems more likely, however, as suggested above, that the drainage of this section of the Allegheny was northward through the Conewango. The valley at Titusville is nearly a mile in width, and becomes gradually larger upon passing northwestward along the line of the Muddy Creek channel, the width being nearly 2 miles along the portion of French Creek between the mouth of Muddy Creek and Cambridge. It is several times the size of the small valley which now forms the lower course of Oil Creek.

The headwater part of Oil Creek drainage basin was excavated to a level below that of the lower part; that is, of the small drainage line south of the divide. The valley floor at Titusville, as shown by numerous oil wells, is only 1,100 feet above tide, and it falls to 1,034 feet in the Muddy Creek channel, 7 miles northwest of Titusville,[1] thus reaching an elevation tion about as low as the lower Oil Creek reached at Oil City on the Middle Allegheny, 18 miles below Titusville as the stream now flows.

The old divide near Titusville is found to consist of a narrow ridge situated but a short distance south of the line of the old upper Oil Creek. It was apparently quite similar to the divide at the head of Pithole Creek, a few miles east of Titusville, which almost overlooks the valley of a headwater tributary of Oil Creek and yet stands about 400 feet above it. The

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[1]See Carll, op. cit., pp. 357–358.

divide at the head of Pithole Creek rises to a height of 1,640 feet above tide, and the rock surface is about 1,560 feet, while the rock floor in the valley on the north is less than 1,200 feet. It is scarcely probable that the divide crossed by Oil Creek south of Titusville stood quite so high. The gap made by the creek is bordered by abrupt bluffs up to a height of only 1,320 feet, which probably marks the height of the old divide. South of this old divide is the small valley of the old lower Oil Creek, leading to the Allegheny at Oil City. Its width, including rock shelves, averages scarcely 100 rods, while the width inside the rock shelves is in places but 40 to 60 rods. It is similar in size to Pithole Creek Valley, which drains a small district on the east. This small valley had been excavated nearly to the present level of Oil Creek before the culmination of the earliest glaciation, for low rock shelves on its borders 40 to 60 feet above the stream are thickly covered with early glacial deposits. Its valley floor is in harmony with that of the neighboring portion of the Middle Allegheny, which was excavated nearly to the present stream level before the glacial deposition took place. An abandoned oxbow channel west of Petroleum Center has a rock floor as low as the creek level, 1,090 feet above tide, and yet it seems not improbable that its excavation preceded the drift deposition.[1] At the Boughton Acid Works, within a mile south of the old divide, the valley floor appears to have stood only about 1,200 feet above tide, or 40 to 50 feet above the creek at the time the reversal took place.

The headwater portions of French Creek and Little and Big Brokenstraw creeks evidently have been greatly modified by the obstruction of old lines of drainage. In several places the waters now divide in the valley-like lowlands which probably were formed by ancient streams. It is probable that the headwater portion of Little Brokenstraw Creek discharged into the valley now occupied by Lake Chautauqua, there being an abandoned valley along the line of the Erie Railway from this creek at Grant, N. Y., to Lake Chautauqua. Evidence that the headwater portion of this creek was once distinct from the lower course is found in the lower altitude of its rock floor, and also in the fact that the headwater portion is in a larger valley than the lower course of the creek. A boring at Lottsville, Pa., in the headwater portion of the creek reached a level 150 feet below the rock floor at the mouth of the creek without entering rock.

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[1] See Carll: Second Geol. Survey Pennsylvania, Rept. I^4, 1883, p. 311.

It was suggested by Carll[1] that currents under the ice may in this instance have excavated to a considerable depth below the level of the main outlet, but it seems hardly necessary to assume that so much excavation had been made through this agency. It is Carll's opinion that the old drainage was northward from Lottsville to the valley of Lake Chautauqua through the abandoned valley just noted.

Possibly a part of Big Brokenstraw Creek also discharged to the Lake Chautauqua Valley and carried with it the headwater portion of French Creek, there being lowland connection with Little Brokenstraw along Coffee Creek and Swamp Run near the north line of Pennsylvania and also from Clymer, N. Y., eastward into the headwaters of Brokenstraw and the abandoned valley referred to above. But it seems more probable that the headwater portion of Big Brokenstraw Creek connected toward the north or west with French Creek and found a northward discharge to the Lake Erie Basin. The lowlands connecting Big Brokenstraw with French Creek are broader and have a slightly lower altitude than those connecting it with Little Brokenstraw Creek. At Corry a broad lowland deeply filled with drift connects Big Brokenstraw with the head of South French Creek. This lowland also connects toward the north through Hare Creek Valley with the main French Creek just above the old divide crossed by that creek in the southwest corner of New York. From the point where this lowland connects with French Creek an old valley leads northward to North French Creek at Findley Lake, and from North French Creek a lowland heavily covered with drift extends northward past Grahamsville to the plain bordering Lake Erie near Northeast, Pa. The filling of drift is so great in these lowlands that at present it is not possible to determine whether there was formerly a northward discharge from Corry through these old valleys into the basin of Lake Erie.

The portion of French Creek Basin in eastern Erie County, Pa., is connected with old valleys leading northward from South French to North French Creek and thence to the headwaters of small tributaries of Lake Erie. The valley of the present creek shows a marked constriction just south of the Erie-Crawford county line, being reduced to about one-fourth the usual width of that portion of the valley. These features seem to favor northward discharge rather than a connection toward the southwest with

[1] Second Geol. Survey Pennsylvania, Rept. I^4, pp. 234–235.

the old Muddy Creek (Upper Oil Creek) drainage. But as yet no line has been traced out to the lake and it is not certain that the constriction on French Creek Valley near the Erie-Crawford county line marks an old divide.

THE LOWER ALLEGHENY AND ITS TRIBUTARIES.

In the discussion of the old Monongahela system (p. 88), attention was called to the broad gradation plain found on the Lower Allegheny, and comparison was drawn between the breadth of that gradation plain and the much narrower rock shelves, abandoned ox-bows, and gradation plains found on the Middle Allegheny system. The Lower Allegheny and all its tributaries lie in large part, if not entirely, outside the glacial boundary. Consequently the several fluvial plains are better displayed than in the Middle and Upper Allegheny where much of the drainage area lies within the glacial boundary and where the old fluvial plains have been greatly concealed by glacial deposits. But even on the Lower Allegheny there have been quite heavy deposits of glacial gravel (60 to 100 feet in depth), made by streams that led down this valley from the ice field to the north, after the old divide which separated the Lower from the Middle Allegheny had been cut away.

The main gradation plain, as determined by aneroid, has a height of 1,020 to 1,040 feet in the vicinity of the mouth of the Clarion River or 150 to 170 feet above the present stream. It falls to about 900 feet at the junction of the Allegheny and Monongahela at Pittsburg and stands at that point very nearly 200 feet above the river. The glacial gravel which caps the gradation plain has an upper limit at about 1,135 feet near the mouth of the Clarion and about 975 feet near Pittsburg. The original lower limit is not known, inasmuch as the amount of trenching prior to the gravel deposition has not been settled.

In the western part of the city of Allegheny a feature was observed which supports the view that the streams had cut somewhat below the level of the old gradation plain before the gravel filling took place. Upon ascending to the old gradation plain along California avenue north of Woods Run the contact between the glacial gravel and the underlying shales is well exposed. The shales are found to be deeply weathered, so that for 1½ to 2½ feet from the surface only a brown residuary clay remains. The surface of the shale here stands about 890 feet above tide and very nearly at the general level of the old gradation plain. The amount of weathering which it had undergone

prior to the gravel deposition seems to indicate that it stood above the old stream for a considerable period before the gravel deposition occurred. But it does not throw light upon the depth to which trenching had reached.

Within the trench cut in the old gradation plain there are a few rock shelves which seem sufficiently near a definite horizon to be correlated. They stand about 75 to 100 feet above the river, and vary in width from one-fourth of a mile to narrow strips but a few feet wide. Whether they are merely an incident in the cutting down of the valley or signify the termination of an epoch of degradation which was followed by a notable halt and possibly a refilling, has not been determined.

There remain two other fluvial plains to be considered. One is the rock floor beneath the present stream and the other is the gravel filling which took place in connection with the Wisconsin glaciation. The rock floor is usually but 20 to 30 feet below the stream bed, though in a few places it appears to reach 50 feet. The excavation down to the rock floor seems to have preceded the Wisconsin stage of glaciation, for the rock floor is found to be as low under undisturbed portions of the Wisconsin gravel as in the trench which the river has cut in that gravel. The filling connected with the Wisconsin glaciation extends to a height of 60 to 80 feet above the present stream, and about 100 feet above the rock floor.

In the table below the relation and altitudes of the several fluvial plains are set forth. The altitudes are largely barometric, but as a base for calculation the Allegheny Valley Railway has furnished a series of levels extending the whole length of the Lower Allegheny. The altitudes of the stream, the surface of the Wisconsin terrace, and the rock floor below the stream were estimated with a fair degree of accuracy from these railway levels, but for the gradation plain, high rock shelves, and the upper limit of gravel on the gradation plain, the barometer was called into use. In the vicinity of Pittsburg, however, Jillson has made a series of measurements of the gradation plain and upper limit of gravel with a Locke level.

Height above tide of fluvial plains along the Lower Allegheny River.

	Distance.	Upper limit of gravel.	Gradation plain.	Lower rock shelves.	Wisconsin gravel filling.	Present stream.	Rock floor.
	Miles.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Mouth of Clarion River	0.0	1,135	1,020–1,040		910	870	(?)
Parker	2	1,115	1,015, 1,060		900	860	840±
Monterey	4.4	1,125	1,000±		885	845	835—
Hillville	3.5		980		870	830	
East Brady	6.1	1,115	(?)		860	825	815
Redbank	5.5	1,100	950		850	815	810
Reimerton	3.6	(?)	(?)		840	807	
Mahoning	4.7	1,050	960	850	825	800	
Kittanning	10.6	1,010	890 and 980		810	770	
Ford	4	1,025	885 and 980		805	765	
Aladdin	10	(?)	(?)		800	740	710
Natrona	4	1,000±			800	730	
Tarentum	5	1,000±	975	825	800	725	700—
Arnold	1	1,011		815	800	725	
Hulton	7				800	720	
Sharpsburg	7.4				800	710	
Pittsburg	2	972	904	800			
Allegheny	3	975	898—		800	698.4	
Bellevue		978	898±				

The interesting series of channels connecting the Lower Allegheny with an old oxbow of the Monongahela River at Pittsburg were mentioned in the discussion of the old Monongahela system, but it may be of interest to consider them in more detail. An old channel of the Monongahela leaves the present stream near Homestead and passes northward to East Liberty (now a part of Pittsburg). It there curves around to the southwest through Oakland and Schenley Park, coming to the Monongahela again about 3 miles below Homestead. This channel, like the gradation plain of the Monongahela, is nearly a mile in average breadth. Its rock floor stands 175 to 200 feet above the present stream, or about the same as the gradation plain. Its northernmost part is only 1 to 2 miles from the Allegheny Valley, but is separated from it by a chain of hills which in places rise 200 to 300 feet above the old channel. There are, however, three gaps in the chain of hills which were sufficiently low to permit the waters of the Allegheny to enter the old oxbow of the Monongahela and

bring into it a heavy deposit of glacial gravel. The easternmost gap is along Negley Run, immediately north of East Liberty, and has a width of nearly one-half mile. The middle gap is along Haights Run, less than a mile west of Negley Run. This gap is scarcely more than one-fourth mile in width. The third or westernmost gap sets in at Allegheny cemetery and extends westward to the base of Herron Hill, being nearly a mile in width. These gaps were filled by glacial gravel to a height of about 75 feet above the rock floor of the old oxbow of the Monongahela, their highest points being 970 to 975 feet above tide, as determined by Jillson with Locke level. The gravel extends but little into the old channel of the Monongahela, a feature which seems to indicate that the gravel-bearing water from the Allegheny there encountered a lagoon with but little current.

All the important tributaries of the Lower Allegheny enter from the east, the divide on the west being but 10 to 20 miles distant from the river. The largest eastern tributary, Conemaugh River, has a drainage area of about 1,800 square miles, or nearly one-sixth of the entire basin of the Allegheny and fully one-third of the Lower Allegheny Basin. The Clarion has a drainage area of about 1,200 square miles, Redbank River 550 square miles, and Mahoning Creek 400 square miles. These four streams drain nearly four-fifths of the area tributary to the Lower Allegheny.

Rising, as these eastern tributaries do, on the border of the Allegheny Mountains, they have very rapid fall and are subject to great freshets in the spring, at which time the melting of snow and heavy rains often unite to swell their volume. The Johnstown flood, on the Conemaugh, is a conspicuous instance of the disasters occasioned by such freshets. These streams are also subject to extremely low stages in the summer months. Porter estimates that the Conemaugh is at times reduced to less than 90 cubic feet per second, or scarcely two-fifths its proportion of the average low-water discharge of the Allegheny River (1,330 cubic feet per second).[1] It is conspicuously lower than the low-water discharge of tributaries that drain drift-covered districts. Thus, French Creek, which has a drainage area of but 1,130 square miles, is estimated to have a low-water discharge of about 700 cubic feet per second.[2]

[1] Water power of the Ohio River Basin, etc., by Dwight Porter: Tenth Census of United States, 1880, Vol. XVII, Pt. II, pp. 442, 445.

[2] Op. cit., p. 448.

Evidence that additions have been made to the upper drainage basin of the Allegheny, is furnished by the features of the tributary valleys. It is found that the trenching of the gradation plains on the tributaries is conspicuous only in their lower courses. On the Redbank River, which enters 22 miles below the Clarion, accurate data are obtainable, since the railroad follows its valley for 70 miles and has a grade nearly coincident with the stream and but a few feet (20 to 40) above it. The profile of this railroad (see fig. 7) brings out the significant fact that the stream has a much more rapid fall in the lower 20 miles of its course than for some distance above that point, which is the reverse of the normal law of mature streams. The average fall for this 20 miles is nearly 12 feet

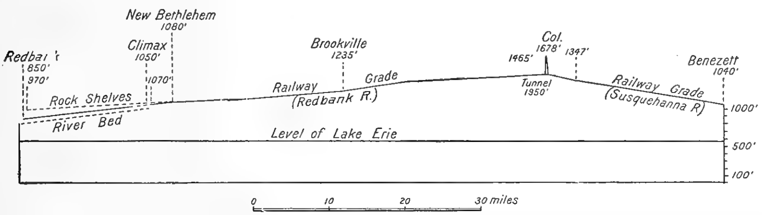

FIG. 7.—Profile along a portion of the Low-Grade Division of the Allegheny Valley Railway (so named because of the low altitude at which it crosses the Allegheny Mountains). It shows the increase in the rate of fall of Redbank River in its lower 20 miles, a feature due to the deeper trenching of that portion. The profile also shows the extreme narrowness of the col which separates the Redbank and Susquehanna systems, the tunnel beneath the col being but 1,950 feet in length.

per mile, while for the next 20, or even 50, miles above, the average fall is less than two-thirds of this. In the upper portion the present floor of the stream nearly corresponds with an old floor. In the lower portion, this old floor continues on to the mouth with a rate of descent a little less than that of the upper portion, following the normal law. The later stream here, however, enters the Allegheny about 150 feet below the old floor; but this lessens rapidly upstream, and at 20 miles above the mouth it is reduced to about 60 feet.[1]

It appears quite evident from these facts that there has been an abnormal deepening of the Allegheny since the formation of the old floor, and that this has been so recent that it has, as yet, made itself seriously felt

[1] Compare statement of I. C. White respecting the relative altitude of water deposits on the upper and lower courses of the Conemaugh, Youghiogheny, and Cheat rivers: Am. Jour. Sci., 3d series, Vol. XXXIV, 1887, p. 378.

upon the gradient of the Redbank only in its lower 20 miles. Such an abnormal deepening is accounted for by the sudden enlargement of the drainage area to several times its former size in consequence of the diversions of drainage previously discussed. It is improbable that a simple change in the altitude, or in the general slope of the region, would produce a result of precisely this nature. The main stream, of course, usually leads in rejuvenated excavation, but not in such a disproportionate degree as this nor in precisely this method.

In the Clarion Valley the present stream has a fall of about 500 feet in the lower 75 miles below Ridgway and the old fluvial plain about 340 feet Redbank River falls about 400 feet in the lower 40 miles below Brookville, but the old fluvial plain falls only about 280 feet. In the 62 miles from Falls Creek station to the mouth of Redbank River, the stream has a fall of 550 feet and the old fluvial plain a fall of 430 feet. The Conemaugh falls about 425 feet, and the old fluvial plain about 300 feet in the 64 miles below Johnstown. Of these old fluvial plains the one on the Clarion shows the lowest fall, about 4.5 feet per mile. If these data are compared with those given in the table on the fluvial plains of the Lower Allegheny, it will be found that both in its present and in its old stream beds the Lower Allegheny has a much lower gradient than its main tributaries.

BEAVER RIVER.

Beaver River is formed by the junction of the Shenango and Mahoning rivers, and has a drainage area of about 3,000 square miles, of which, perhaps, 1,800 square miles are in Pennsylvania and the remainder in Ohio. Attention has already been called to the evidence that the Beaver constituted the former line of discharge for the Upper Ohio and its main tributaries as far to the northeast as the Clarion River. The restoration of the old system of drainage given on fig. 1 (p. 89) serves to show its naturalness compared with the present system. The Conoquenessing, an eastern tributary, has a northwestward trend to its junction with the Beaver, and formerly continued in this direction toward the Lake Erie Basin, but now it turns abruptly southward to enter the Ohio. The former outlet of Slippery Rock Creek was in a course north of west through the valley now drained by Big Run entering the Shenango at Newcastle. This finds a natural continuation northwestward along the old line to Sharon, Pa. The upper course of Mahoning River is northward from its source in Columbiana

County to the head of Grand River Basin near Warren, Ohio, through which it formerly evidently discharged. It now makes an abrupt turn to the southeast along a small valley which apparently headed near the Ohio-Pennsylvania line. Smaller tributaries illustrate still further the unnatural courses of the present lines of discharge.

In connection with this drainage system, it is necessary to consider several distinct fluvial plains. The gradation plains and rock shelves which slope toward Lake Erie from the mouth of the Beaver are the earliest of the series. The gravel filling which built up the lower part of the Beaver and the Upper Ohio sufficiently high to give a discharge down the present Ohio comes next in the series. A rock floor cut to a lower level than the beds of the present streams apparently forms the next well-defined fluvial plain. A gravel filling which occurred during the Wisconsin stage of glaciation evidently succeeded the deep excavation of the valleys, and comes later in the series. This gravel filling is now in process of excavation by streams whose beds form the last of the series of fluvial plains. Attention will be here directed only to the main gradation plain, to the rock floor buried beneath the present streams, and to the gradients of the stream beds The gravel fillings are considered in connection with their respective drift sheets.

The gradation plain has been greatly disguised by a drift coating, except in the lower course of the Beaver. It apparently descends northward along the Beaver and the Shenango, as outlined on a preceding page, about to Sharon, Pa., but it does not appear to continue its descent along the Shenango north of that city. At Greenville, 25 miles above Sharon, a series of wells test the valley quite widely and strike a rock floor, apparently the old gradation plain, at a level about 35 feet higher than the level of the old plain at Sharon. This condition fits in naturally with the interpretation that the old drainage passed westward from Sharon into the Grand River Basin. At Youngstown, Ohio, which is on the line apparently followed by the old stream, the gradation plain appears to be lower than at Sharon, though the valley has not been explored sufficiently to make certain the precise altitude of the gradation plain. At Niles, also on the old line, the rock floor in one boring was found to be 65 feet lower than at any ascertained borings in the vicinity of Youngstown. Borings in the Grand River Basin near Southington, Mesopotamia, and Rome, Ohio, have

in several instances reached a level only 70 to 80 feet above Lake Erie without striking the rock floor, but one boring near Mesopotamia is thought to have reached rock at a level 70 feet above Lake Erie.

As the gradation plain at the mouth of the Beaver stands nearly 300 feet above Lake Erie and is distant but 90 to 100 miles from some of these borings in Grand River Basin, it is evident that the northward slope is rapid. In the 30 miles from the mouth to the head of the present Beaver there appears to be a descent of fully 50 feet, and in the 50 miles to Sharon of about 85 feet, thus giving an average slope of about 20 inches per mile. This slope has possibly been made greater by Pleistocene changes in level, though specific evidence is not at hand.

The old gradation plain and the rock floor of the valley excavated in it are widely separated in altitude near the mouth of the Beaver, but apparently approach each other rapidly in passing northward. The evidence seems clear that the reversal of drainage took place before much of the deep channeling occurred.

In general the slope of the rock floor beneath the present streams is in harmony with the present drainage, and in the main is the reverse of the ancient system. There is, however, a part of the channel in which the rock floor appears to be excavated to a level too low to correspond with the floor at points lower down the stream. Such features were at first interpreted to signify that the drainage was in the reverse direction from the present line of discharge, but further examination has rendered it probable that the excavation has been accomplished by a stream running in the present line of discharge. On the lower course of the Mahoning the oil-well records show the rock floor to be fully as low as at the mouth of the Beaver and apparently about 90 feet lower than at the mouth of the Conoquenessing, midway of the Beaver Valley and 15 miles below the mouth of the Mahoning. The piers of the railway bridge at the mouth of the Conoquenessing are reported by R. R. Hice, of Beaver, to stand upon the rock floor, and are so distributed as to test the middle as well as the border of the valley. Upon passing up the Mahoning, a few miles from the deeply excavated part, the rock floor is found to have an altitude nearly 150 feet higher. There is an abrupt descent just above Edenburg. Here the buried floor seems to fall 165 feet in half a mile, as shown by four wells reported by W. H. Raub, of Edenburg. The declivity may be even

more precipitous, as the wells are not situated so as to limit more closely the space occupied in the descent. The variations in the valley floor appear to be such as might result from the recession of a fall or cascade, and this suggestion harmonizes with the more clearly indicated history of the region, which appears to be as follows:

Before the ice invasion forced the waters of the upper portion of the Grand River Basin across the divide, which apparently stood near the State line above Edenburg, there was only a small tributary leading down to the valley occupied by the old north-flowing Monongahela system. But when the waters of the upper Grand River Basin were forced over the divide in large volume and descended the steep slope of the little valley, deep scouring at the mouth would naturally result and the formation of cascades or falls would readily follow. These would work upstream as the erosion progressed. They appear to have reached a point just above Edenburg when a later incursion of the ice stopped the process and filled the deep valley with débris. The formation of a pool was favored by the softness of the rock in this portion of the valley and the hardness of the strata encountered near the mouth of the Conoquenessing.

The present system of drainage displays considerable variation in the slope of its stream beds, some portions being very sluggish, while other portions present rapids and even low cascades. The Shenango falls but 2 to 2½ feet per mile in the upper 22 miles above Jamestown, Pa., the source of the river being in a swampy lowland at an altitude only 1,025 feet above tide. In the next 30 miles, from Jamestown to Sharon, there is a fall of 4 to 5 feet per mile. From Sharon to the mouth of the Shenango, a distance of 24 miles, the average fall is 2½ feet per mile. The Mahoning has a fall of about 3 feet per mile in the 35 miles from Warren, Ohio, to its mouth, but the northward-flowing headwater portion is more rapid. In the 23 miles from its head to Beaver Falls the descent of the Beaver is only about 2 feet per mile, but in the lower 5 miles it makes a descent of 52 feet, or more than 10 feet per mile.

The principal data concerning the several fluvial plains which form the basis of the above discussion are grouped in the following table:

Height above tide of fluvial plains along the Beaver and Shenango rivers.

Location.	Distance.	Gradation plain.	Buried channel.	Present stream.
	Miles.	*Feet.*	*Feet.*	*Feet.*
Mouth of Beaver River	0	865 to 880	605±	664
Beaver Falls	5	855±	615±	716
Mouth of Conoquenessing River	9	840	682	734
Head of Beaver River	14	810±	620±	764
Newcastle	3	....	645	780
Harbor Bridge	4	800	?	800
Sharon	17	780	?	840
Clarksville	5	?	760—	860
Greenville	20	815	?	940
Jamestown	5	?	?	965
Outlet of Pymatuning Swamp	13	?	?	1,000
Head of Pymatuning Swamp	9	?	?	1,025

LITTLE BEAVER RIVER.

The Little Beaver, a small north tributary, flows into the Ohio near the Ohio-Pennsylvania line. Its drainage area lies mainly in Ohio, though the North Fork has much of its watershed in Pennsylvania. The northern half of the area drained by the Little Beaver has been glaciated, and its preglacial features are greatly obscured by heavy deposits of drift. Its general elevation is scarcely so great as the unglaciated southern half. This and other features suggest that much of this drainage basin once had a northward discharge to the old Beaver system. The lower course of the present stream is very narrow, and in preglacial times may have carried but a small fraction of the present drainage. The probable course or courses of northward drainage and the extent of change in drainage have not been determined. White reports that the North Fork has a sluggish flow through a region heavily covered with drift from its source nearly to its junction with the main creek at Fredericktown, Ohio, but that below that junction the stream falls at the rate of 25 feet per mile.[1]

[1] Second Geol. Survey Pennsylvania, Rept. Q, 1878, p. 6.

MUSKINGUM RIVER.

The Muskingum River drains the greater part of eastern Ohio and has an area of about 7,740 square miles. The name Muskingum is applied only to the lower portion below the junction of the Tuscarawas and Walhonding rivers, a length of 109 miles. From the sources of the Walhonding and Tuscarawas to their junction is a distance of about 100 miles, thus giving the basin a length of 200 miles. It is a broadly branching drainage system at the north, with an extreme width of about 100 miles. At the south it receives few tributaries, there being none of importance below Zanesville.

The following estimates of the areas of the drainage basin are taken from Porter's census report:[1]

Drainage areas of Muskingum River and its tributaries.

	Square miles.
Walhonding River	2,159
Tuscarawas River	2,547
Wills Creek	815
Licking River	703
Muskingum and tributaries below Zanesville	1,175
Total area of Muskingum system	7,740

This drainage basin is mainly in the unglaciated portion of southeastern Ohio, and the greater part of it is in soft Coal Measures strata, which have become greatly broken down under atmospheric and stream action. On the northwest border of this watershed the hard sandstones and conglomerates which underlie the Coal Measures come to the surface. These, in some cases, are preserved as outlying knobs and ridges, standing 200 to 300 feet or more above the lowlands that surround them. The most elevated parts of the watershed are found in these outlying knobs, some of which are nearly 1,500 feet above tide. The eastern border of the watershed is also high, its altitude reaching about 1,400 feet. In the central portion of the watershed the uplands are but 900 to 1,000 feet and the valleys 700 to 800 feet above tide.

Many of the valleys are broad and characterized by gently sloping bluffs. The old gradation plains in much of the area stand below the level of the present streams. The large amount of gravel filling in valleys that lead away from the glaciated area has built up the stream beds to such an

[1] Tenth Census of the United States, 1880, Vol. XVII, Part II, p. 466.

extent that the tributaries leading in from unglaciated portions of the basin have become silted up to a marked degree. In these respects a striking contrast is found between this drainage system and that of the Upper Ohio, which lies immediately east of it.

Notwithstanding the low altitude of the gradation plains and consequent absence of trenches, the present system of drainage departs greatly from the ancient system. Not only have changes occurred in the glaciated district, but also outside, notably in the line of discharge for the main river. The filling of the valleys was sufficient to raise the streams above the level of the low cols that separated the ancient drainage lines without the necessity of much excavation at the cols. The present drainage lines are almost entirely in old valleys, for the divides crossed by them constitute but a small portion of the length of the streams. The position of the old divides is usually shown by a constriction in the valleys combined with a higher altitude of the rock floor. The changes are numerous in the headwater portions that lie within the glacial boundary, but only a few have been sufficiently examined to justify an interpretation. In some cases where constrictions occur in the valleys there have been no borings sufficiently deep to throw light upon the altitude of the rock floor, thus leaving an element of uncertainty concerning the significance of the constriction. The changes of drainage in the central and western portions of this watershed, and also along the lower course of the valley, have been investigated by W. G. Tight in some detail, but his latest results have not yet been published. The writer has given the region only a hasty reconnaissance. The changes in the northern portion have also been investigated by J. H. Todd, of Wooster, Ohio.[1] In the eastern part of the watershed no changes of importance appear to have taken place. M. C. Read,[2] of the Ohio survey, has outlined on a map, and to some extent discussed, the position of many preglacial lines, some of which are not followed by the present streams, but he did not attempt such a full interpretation of the connections of the old lines of drainage as has been made by Tight and other later students.

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[1] Ohio Acad. Sci., Special Papers No. 3, 1900, pp. 46–67.

[2] Geology of Huron, Richland, Knox, and Licking counties, Ohio, by M. C. Read: Geology of Ohio, Vol. III, 1878, pp. 289–361. Also Geology of Ashland, Wayne, and Holmes counties, Ohio, by the same author: Ibid., pp. 519–561.

THE OLD WESTWARD OUTLET.

Tight has shown that the greater part of the Muskingum drainage system was formerly connected with the Scioto system by a broad valley leading from Dresden (a few miles above Zanesville) westward past Newark to the Licking reservoir and thence into the Scioto Basin near Circleville.[1] The present southward course past Zanesville is through a much narrower valley than the old line leading westward to the Scioto Basin, and the rock floor is markedly higher along the present course of the Muskingum than along the old course.

Along the old line of discharge there is, for about 10 miles, an open valley, 1 to 1½ miles in width, leading westward from Dresden past Frazersburg. This open valley is now drained by a small stream, Wahatomaka Creek, which enters it from the north near Frazersburg. The old outlet of the Muskingum continues broad and open as far west as the eastern border of Licking County, where it becomes obstructed by a great accumulation of drift, which fills the valley to a height of 150 feet or more above the level of the broad bottom on the east. This drift filling obstructs the valley in this manner for only a couple of miles, and even there but half fills it, for the bluffs rise about 300 feet above the broad bottom just mentioned. At Hanover an open valley sets in, which extends westward to Newark and thence southwestward along the South Fork of Licking River to the vicinity of the Licking reservoir, where it is so filled with drift as to render its further course difficult to determine. A series of gas borings, however, indicate that it passes southward about to Hadley Junction and there turns westward, passing near Canal Winchester and Groveport and coming to the Scioto River about midway between Columbus and Circleville, where it seems to have joined the old Kanawha system.

The course or choice of courses for the old Kanawha from this point has already been discussed (p. 103). It should be stated, however, that Tight inclines to favor the northwestward course across the rim of the Scioto Basin into the old Wabash system rather than the northward course along the axis of the Scioto Basin to the Lake Erie Basin.

The old line of discharge from the Muskingum into the Scioto Basin was excavated to a level much below the broad bottoms above described.

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[1] Bull. Denison Univ., Vol. VIII, Pt. II, 1894, pp. 35–61.

A well about 1 mile east of Hanover is reported by Tight to have reached a depth of 218 feet without striking the old rock floor of the valley, though the bottom of the well is about 150 feet below the present level of the Muskingum at Dresden, or but 550 feet above tide. It is 50 feet or more below the level of the rock floor of the present Muskingum at points 30 to 40 miles below Dresden. At Newark the old valley was cut to a level about 250 feet below the present river, or to less than 550 feet above tide. Gas wells at Hadley Junction and other points along the old line between Hadley and the Scioto River also reach a similarly low level before encountering rock.

THE PRESENT LINE OF DISCHARGE.

Turning now to the present course of the Muskingum below Dresden, we find a much narrower valley than the old channel of discharge, the width ranging between one-half and three-fourths of a mile in the first 25 miles below Dresden. It there grows narrower, and in the vicinity of the line of Muskingum and Morgan counties, 33 miles below Dresden, it is less than one-fourth of a mile in width and is bordered by abrupt bluffs 200 to 250 feet in height. This is the narrowest place on the lower course of the river and is apparently the site of an old divide. The valley, however, remains narrow nearly to the mouth of the stream, its measured breadth at Lowell, 12 miles above the mouth, being barely one-half mile.

No data concerning the elevation of the rock floor in the portion of the valley between Dresden and the supposed old divide have been obtained; but at Eaglesport, about 3 miles below the supposed divide, a gas well on the east side of the river about midway between the bluffs entered rock 30 to 35 feet below low water, or about 615 feet above tide. Another boring at McConnelsville, 7 miles farther down the valley, is reported to have entered rock 50 feet below low water at that point, or 590 feet above tide.[1] The rock floor here seems to be about as low as at Lowell, 35 miles farther down the valley, the dam at Lowell being built upon the rock floor in the middle part of the valley which there stands at 580 to 590 feet above tide.

Concerning the height of the supposed divide above Eaglesport, there is good evidence from the contours of the bluff that it did not exceed 900 feet above tide, for the bluffs rise abruptly in this constricted portion to a

[1] Data concerning the borings at McConnelsville and Eaglesport were obtained from Dr. H. L. True, of McConnelsville.

height of only 875 to 900 feet. Possibly the old divide was even lower. In districts both to the east and west of the supposed divide on the Muskingum, cols are found at an altitude not far from 900 feet above tide, and this also favors the view that the col crossed by the Muskingum stood equally low.

DEPOSITS ON THE LOWER COURSE OF THE MUSKINGUM.

In the portion of the Muskingum Valley between Dresden and the supposed divide, glacial deposits, probably of Wisconsin age, have been built up to a level 750 to 800 feet or more above tide, or about 100 feet above the present stream. They appear to be as high in Zanesville, at the mouth of the Licking River, as in the portion of the valley above, between Zanesville and Dresden. Below Zanesville the altitude apparently declines about as rapidly as the descent of the present stream, being by Locke level from the Government bench marks 85 feet above the river near Taylorsville, 90 feet at Eaglesport, 110 feet near the mouth of Meigs Creek, 119 feet at Beverly, and 105 feet at the mouth of the Muskingum. In the 75 miles from Zanesville to the mouth of the Muskingum the present stream descends from 683 to 570 feet above tide, while the gravel surface descends from 800 to 675 feet above tide. Before this gravel was carried down the valley there apparently had been an excavation at the supposed divide to a level 30 to 35 feet below the present stream or to less than 625 feet above tide.

Deposits of waterworn material have been found in the lower part of the Muskingum Valley at higher elevations than the glacial gravels. In the south part of McConnelsville a rock shelf standing about 775 feet above tide, or 135 feet above the river carries a deposit of gravel several feet in depth. No rocks of glacial derivation were observed in this gravel, while in the gravel which appears at a lower elevation such rocks are abundant. Dr. True, of McConnelsville, reports that at a point about 1 mile above Stockport pebbles occur up to a level about 180 feet above the river, or 810 feet above tide. These include pieces of the Cambridge limestone, whose outcrop is up the river from this point, showing clearly that the deposit was made by a southward-flowing stream. Near this point a col was found at an altitude of about 830 feet above tide, which appeared to True to show evidence of excavation by a stream. At Luke Chute, True found pebbles on the slope of the valley up to a height of 160 feet above the river, or 780

feet above tide. In that vicinity he also found a few small quartz pebbles in a surface loam capping the upland at about 840 feet above tide.

In this connection it may be remarked that small stones apparently derived from the drift, including greenstone, granite, and quartzite, are scattered over the uplands in the vicinity of McConnelsville at various altitudes up to 1,000 feet above tide. True has collected about a half bushel of these erratics. As the glacial boundary seems to lie several miles northwest of McConnelsville, it may be necessary to refer the distribution of these erratics to human agency. The Indians were perhaps responsible for their wide distribution outside the glacial boundary. The small pebbles found in the surface loam, which are usually a half inch or less in diameter, and are found at a depth of 1 to 4 feet from the surface seem more likely than these larger pebbles to have been deposited by natural agencies. The surface loam is apparently a water deposit, possibly a phase of the loess, as indicated on a subsequent page. The loam and its included pebbles point strongly to an interval of submergence which antedated the Wisconsin gravel filling in the valley of the Muskingum, but which may be more recent than the change of drainage just discussed. The subject is one requiring further investigation.

STRIATED BLOCKS IN MUSKINGUM VALLEY NEAR M'CONNELSVILLE.

True called the writer's attention to striated sandstone blocks found on the slope of the east bluff of the Muskingum about 2 miles above McConnelsville, at an altitude 780 to 800 feet above tide. They apparently were derived from the ledges in the immediate vicinity. The striation consists of a series of shallow grooves, which vary a few degrees in trend and seem less regular than glacial striæ. The writer has observed a grooving more marked and regular than is here exhibited on a rock reef in the bed of the Ohio River near Ravenswood, W. Va. As that locality is far outside the glacial boundary, the grooving is apparently due to river ice. It seems not improbable, therefore, that the grooving displayed by these blocks is referable to the transportation of stones by river ice when the stream was flowing at an altitude as high as these ledges.

EXTENT OF THE OLD MUSKINGUM DRAINAGE BASIN.

The old Muskingum drainage basin extended up the Tuscarawas nearly to the mouth of One Leg Creek, a distance of 75 miles above the

old westward outlet. The eastern tributaries of the Tuscarawas and Muskingum between the mouth of One Leg Creek and the south line of Muskingum County probably had as great an extent then as at present; but the northern and western tributaries of the Tuscarawas and Muskingum all appear to have been quite small. The Walhonding, which now has a drainage area of more than 2,000 square miles, appears to have formerly drained scarcely 500 square miles, its basin being mainly in Coshocton County. It received only the 8 miles of the lower course of Owl Creek below Millwood and the lower 8 or 10 miles of Mohican Creek. How much of Killbuck Creek was tributary to the Walhonding has not been determined, though it appears probable that the old divide was below the village of Killbuck, or less than 20 miles from the mouth of the stream. Sugar Creek, which enters the Tuscarawas at Canal Dover, is almost entirely a new accession, the old divide being apparently south of Strasburg, only 6 or 7 miles from its mouth. From these observations it appears that the entire drainage area discharging westward past Dresden can scarcely have exceeded 3,000 square miles, which is but little more than half the area that now discharges southward past that point.

It has not been decided whether the old drainage of the portion of the Muskingum south of the westward outlet led northward from Zanesville along the present stream (reversed) to the old outlet at Dresden or took a northwestward course from Zanesville, along a line followed in part by the Licking (in reverse direction), to enter the old outlet near Nashport. Along either line there is only a narrow valley scarcely one-half a mile in average width. Drift accumulations in the northwestward line so conceal its channel that some uncertainty is felt as to its continuity; but it is the more direct line and appears to be fully as capacious as the northward line. In its favor there is also a peculiarity of drainage at Zanesville. An old valley leaves the present Muskingum just below Zanesville and bears northwestward through the western part of the city, being separated from the present river by a prominent ridge known as Putnam Hill. It there connects with the old channel leading up the Licking. It also connects eastward with the Muskingum, but this may be simply the old line of westward discharge for a small drainage basin north and east of Zanesville. In case there was an old divide on the present line of the Muskingum between Dresden and Zanesville it is more likely to have been near Ellis

than at points above or below, for the valley is exceptionally narrow there. The bordering uplands also reach a higher elevation there than in other parts of this section of the Muskingum.

DRAINAGE TRIBUTARY TO THE WESTWARD OUTLET.

The portion of the westward outlet between Dresden and Newark apparently received the drainage from about the same territory as is now tributary to Wahatomaka Creek and the lower course of Licking River. The headwater portions of the North Fork and the Middle or Raccoon Fork of Licking River appear to have discharged directly westward into the Scioto Basin, as determined by Tight, there being an old divide crossed by the Raccoon Fork near Granville, and by the North Fork south of Utica.[1] The South Fork of Licking once received a larger drainage from the east than it does at present. Jonathan Creek, which now leads eastward into the Muskingum from near the Licking reservoir, crosses an old divide at the narrows in its lower course near Fultonham, as determined by Tight and Davis.[2] The greater part of the old drainage was in the reverse direction from the present stream, and entered the old outlet near the Licking reservoir. Farther south the old outlet received the headwater portion of Hocking River from as far down as Rockbridge, in northern Hocking County, including the entire drainage basin of Rush Creek. It also received the drainage of the district now tributary to Little Walnut Creek, a portion of the outlet now being followed by the creek.

CHANGES IN OWL CREEK DRAINAGE BASIN.

Owl Creek, which drains the greater part of Knox County and adjacent parts of Morrow and Richland counties, unites with Mohican Creek in western Coshocton County to form the Walhonding River. It is the first drainage line of importance that leads into the Muskingum from the west above the old outlet. The changes of drainage which it has experienced were partially worked out and discussed by Read prior to 1878.[3] The writer examined the drainage basin in 1890, and subsequently it was examined by Tight and his assistants. It has been noted by each of the persons who have examined this drainage basin that the stream crosses an

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[1] Communicated to the writer.

[2] Modification in the Jonathan Creek drainage basin, by H. J. Davis: Bull. Denison Univ., Vol. XI, 1899, pp. 165–173.

[3] Geology of Ohio, Vol. III, 1878, pp. 325–326.

old divide between Mount Vernon and Gambier, cutting off a spur that projected from the north, and separating a valley that leads southward from Mount Vernon from one that leads southwestward from Gambier. It was also noted by each that another old divide is crossed a few miles below Gambier, near Millwood. Concerning these changes Read remarks:[1]

> For a part of the distance between Mount Vernon and Gambier the stream has made for itself an independent channel through rock spurs projecting from the north, but the course of the old river can be traced a little to the south of it. At Gambier it is in the ancient bed of a channel extending southward toward Martinsburg, now filled with gravel and sand hills, and occupied by Big Run, which flows northward in a direction opposite to that of the old stream, and becomes a tributary of Owl Creek. At Millwood also the channel of Owl Creek is narrow, rock bound, and recent, but the old channel is easily traced to the south of the massive bluffs of the Waverly conglomerate, where it is now filled with modified drift hills of gravel and sand.

The old channel referred to by Read leads past Danville to Mohican Creek at Gann, and is utilized by the Cleveland, Akron and Columbus Railroad. It is evident from the remarks just quoted that he thought the old course of drainage from Gambier was southwestward, but it is not so clear that he thought the old channel that connects Mohican Creek and Owl Creek also had a southwestward discharge. To the writer and also to Tight it seems necessary to give the old channel a southwestward discharge, for it appears to be continuous with the channel to the southwest that discharged in that direction.

Read thought that there was a line of southward drainage from Mount Vernon to Newark through a lowland tract followed by the Baltimore and Ohio Railroad, but he appears to have overlooked evidences of an old divide on this line south of Utica. Upon examining this lowland in 1890 the writer found low rock hills in its midst about 3 miles south of Utica, which seem to bar out completely a southward course for the old drainage. At that time no clue to the old course of drainage could be found, but subsequently it was ascertained by Tight, through data furnished by wells, that the discharge may have been westward from near Utica past Homer to the Scioto Basin. The drift filling is so great along this westward line as to completely conceal its course. At Homer the drift has a depth of 400 feet.

It now seems probable that the greater part of the Owl Creek drainage basin above Mount Vernon formerly had a southward discharge to the bend

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[1] Some typographical errors in Read's description are here corrected.

of the North Fork of Licking River east of Homer, where it was joined by a drainage line leading in from the northeast past Danville and Gambier. The united waters then passed westward into the Scioto Basin. It is not yet known how much of the basin of Mohican Creek was tributary to this line, but judging from the small size of the old valley at Danville it was probably only a small part. Possibly it included only the section between the high ridge at the north line of Knox County and a narrow part of the Mohican Valley a short distance below the point where the old valley turns off toward Danville, a section about 12 miles in length. This leaves a stream about 8 miles in length on the lower course of Owl Creek and a similar stream on the lower course of Mohican Creek to form the old headwaters of the Walhonding River.

CHANGES IN CLEAR FORK OF MOHICAN CREEK.

Clear Fork drains a small district immediately north of the drainage basin of Owl Creek. Its headwaters are in eastern Morrow and southwestern Richland counties in a moraine that forms the east border of the Scioto Basin. The moraine has in that vicinity an altitude of 1,300 feet or more. From the moraine the several headwater streams flow east and southeast and unite a short distance west of Bellville. The stream then passes into a more elevated hilly region whose highest points are nearly 1,500 feet above tide. The valley at the west border of these hills is more than one-half mile in width, but upon passing eastward down the present stream it narrows and finally becomes a contracted gorge just above Newville, where the rock bluffs are scarcely 100 yards apart. This evidently marks the position of an old divide.

Below this divide the old drainage was eastward, as at present, but it apparently was a short distance north of the present stream, along a line now followed in part by Black Fork. The present course is across points on the slope south of the old valley. This departure from the old line is due to a moraine that follows the north side of the present stream from Perryville eastward and prevents the stream from following the old line.

CHANGES IN OTHER HEADWATERS OF MOHICAN CREEK.

There are several other headwater tributaries of Mohican Creek in Richland and Ashland counties which, like Clear Fork, have their sources outside of the highest country included in their basins. The most impor-

tant are Muddy Fork, Black Fork, Jerome Fork, and Lake Fork. The sources of each of these tributaries is in a morainic system that here constitutes the continental divide. It is evident that this morainic system is north of the old divide, for it stands on a slope facing toward Lake Erie. Its altitude is 200 to 300 feet lower than the hills a few miles to the southeast. Furthermore, it is traversed by buried valleys, 250 feet or more in depth, which lead northward from the high upland just referred to toward the Lake Erie Basin. These valleys are now nearly concealed, but well borings have shown their great depth. The old divide on each of these headwater streams of Mohican Creek was probably but a few miles south of the present divide, as the lower courses of the streams, as indicated below, appear to connect with a valley that leads eastward toward the old Cuyahoga Valley; but as yet the old divides have not been located with precision. At the present time the streams flow over passes or cols which were once much lower than the hills of that region. Probably some of these cols stood below the general level of the drift filling. In such cases they may perhaps be located by well borings or by careful examination of the valley contours; though, unfortunately, the drift in these old valleys is aggregated in knolls and ridges that greatly obscure the preglacial topography. On one of these tributaries, Muddy Fork, the valley filling was such that the stream made a detour of several miles near Lucas through a hilly district north of the old valley. This serves to show that there were low passes by which the drainage systems could easily be reversed or otherwise changed.

J. H. Todd, has recently called attention to evidence that the lower courses of these tributaries of Mohican Creek had an eastward discharge.[1] There is a continuous valley or lowland with an average width of about a mile, followed by the Pittsburg, Fort Wayne and Chicago Railroad from Mansfield to Wooster, Ohio. It follows down Muddy and Black Forks (except for the detour of Muddy Fork above noted) to Loudonville, thence eastward across the divide between Black and Lake forks and across the divide east of Lake Fork into Killbuck Valley near Shreve, up which it passes to Wooster. East of Wooster there is a great drift accumulation rising nearly 200 feet above Killbuck Valley, but it is Todd's opinion that the old valley continued in that direction about 10 miles, to the vicinity of Orrville, where a valley is found with very low

[1] Ohio Acad. Sci., Special Papers, No. 3, 1900, pp. 49–55.

rock floor. This valley seems to have drained northward either to Rocky River or the Cuyahoga, passing near Sterling. The writer is inclined to favor the view that this valley had a course eastward from Sterling to Warrick, and thence north past New Portage and Copley Marsh into the old Cuyahoga, that being a larger valley than the old Rocky River Valley. Todd, however, favors Rocky River Valley as the line of discharge into Lake Erie. The valley under discussion, with its deep filling of drift, shows general eastward descent, as indicated in the table below. The available data concerning the rock floor shown in the table, though meager, also favor the view that it slants eastward. It furnishes a more natural trunk line than any other old line of drainage yet found in that region. The several tributaries of Mohican Creek converge toward this old valley, and seem to find in it a natural line of discharge. This old line may properly be termed the old Mohican. The table presents the railway stations in order from west to east between Mansfield and Wooster, showing elevations of the present surface and rock floor so far as known. The borings at Millbrook and Wooster fail to reach rock at the altitudes given.

Altitudes above tide along the old Mohican drainage.

Station.	Distance from Mansfield.	Present surface.	Rock floor.
	Miles.	*Feet.*	*Feet.*
Mansfield	0	1,151	900
Lucas	7	1,090	(?)
Perrysville	14	992	(?)
Loudonville	18	974	825
Lakeville	24	939	(?)
Shreve	30	911	(?)
Millbrook	32	900	715—
Wooster	40	901	790—

Black Fork now turns south from this old valley at Loudonville, and passes through a range of hills to join Lake Fork. Lake Fork passes across the old valley at Lakeville, and discharges through a much narrower valley toward the south. It seems probable that an old divide which separated this drainage system from the east fork of the old Owl Creek drainage was crossed just below the junction of this old valley and Black Fork. For a few miles north of Lakeville Lake Fork is in a broad valley,

but farther up the valley, near the mouth of Jerome Fork, it passes through a narrow channel among the hills. The old valley lies west of this narrow channel. Whether it connects at the north with Jerome Fork has not been ascertained.

KILLBUCK CREEK.

This creek now drains the western part of Wayne and the greater part of Holmes County, flowing southward into the Walhonding a short distance above the head of the Muskingum. It apparently is flowing in the main in the reverse direction from its old course. The headwater portion, down to within 8 or 10 miles of Wooster, found its old line of discharge northward past Lodi to the Black River, a tributary of Lake Erie. A boring recently made in this old valley near Lodi is reported by Todd to have reached a level less than 700 feet above tide without entering rock, the depth of the boring being 210 feet.

It is quite certain that the old valley which leads northward along the Killbuck, as above noted, from Shreve to Wooster did not continue along this creek beyond Wooster, for there is only a narrow valley for several miles above Wooster, the width between rock bluffs being in places less than one-fourth of a mile. The continuation of that old valley (the old Mohican) was probably eastward, as suggested by Todd.

A large part of Killbuck Valley apparently once discharged northward to the old Mohican, for there is a marked narrowing of the valley in passing southward down the present stream. Beneath the glacial gravel the valley is also filled with a fine silt, which was probably deposited in a pool of water that found outlet to the south only after rising above the level of a divide on the lower course of the creek. This silt is a conspicuous feature below Millersburg at least to the village of Killbuck, and seems to indicate that the divide was south of that village. That portion of the valley is narrow and winding, as if it had once constituted the headwaters of drainage lines, but the precise position of the old divide was not determined. After this divide had been surmounted the south-flowing stream carried down the valley to the Muskingum a large amount of gravel of Wisconsin age that is now preserved in the form of terraces on the valley borders.

OLD UPPER TUSCARAWAS DRAINAGE SYSTEM.

It was noted above (p. 158) that the Tuscarawas crosses an old divide between the mouth of One Leg Creek and Canal Dover. This is one of

the most plainly marked instances of the crossing of an old divide to be found in northern Ohio. The Tuscarawas, whose valley above the mouth of One Leg Creek is fully one-half mile in average width, enters a gorge below the mouth of this creek which is scarcely twice the width of the stream, or but 150 to 200 yards. The gorge is a winding channel about 4 miles in length, which was probably mainly drained southward to the Lower Tuscarawas, for the old divide appears to be within a mile of its north end. In this gorge, 1 to 2 miles below the mouth of One Leg Creek, the river is running on the rock floor. Above the gorge, at the mouth of One Leg Creek, the rock floor is known to be more than 100 feet below the stream bed, a boring on its flood plain having failed to reach rock at a depth of 130 feet. A few miles below the gorge, at Canal Dover and New Philadelphia, borings have shown the rock floor to be nearly 150 feet below the stream bed. There is, therefore, not only the marked constriction of the valley, but also the presence of a concealed rock divide to prove that the Tuscarawas is there opening a new channel.

The small size of this gorge compared with other channels across old divides in this part of Ohio is a matter on which further light is needed. The gorge is much smaller than the part of Sugar Creek Valley near Strasburg, which, as noted above, is thought to have been opened by a reversal of drainage. These disparities in size may prove to be due simply to difference in resistance afforded by the rocks in the two localities, for the valleys of that region present surprising variations in width, which seem due solely to rock texture. For example, the valley of One Leg Creek, whose usual width in its lower course is less than one-half mile, expands near New Cumberland to a width of more than a mile and then contracts near its mouth to a width of about one-third of a mile. The valley of the Tuscarawas at Canal Dover is exceptionally broad, being more than a mile in width, yet it appears to be the headwater portion of the old Lower Tuscarawas. In case rock texture proves inadequate to account for the exceptionally small size of this gorge across the old divide, it becomes necessary to consider whether its opening does not date from the Wisconsin stage of glaciation, while the opening of the broader channel in the lower course of Sugar Creek dated from an earlier invasion. The consideration of this question would also carry with it an inquiry into the question whether the lower course of Sugar Creek may have furnished the southward line of

interglacial discharge for the Upper Tuscarawas drainage. These matters can scarcely be decided in the present stage of investigation. It can only be said that there appears to be nothing in the features of the region that would have seriously interfered with the interglacial drainage of the Upper Tuscarawas through the lower course of Sugar Creek.

Above this old divide the drainage was formerly northward to the Lake Erie Basin. One Leg Creek was the main line of headwater drainage, but at Bolivar Sandy Creek entered from the southeast, and at Navarre Sugar Creek entered from the southwest. The course of the old stream from this point is less easy to determine, for the drift is so heavy in that region that the old valleys are in places completely filled. It may have left the Tuscarawas Valley and passed eastward along an abandoned valley, in which Richville stands, to the vicinity of Canton, though quite as probably that abandoned valley was the line of westward discharge for an eastern tributary that drained the headwater portion of Nimishillen Creek. In that case the old stream passed northward along the Tuscarawas Valley. That valley above Navarre seems wide enough as far north as Massillon to have carried the drainage of the old stream, but from Massillon to Clinton, a distance of about 12 miles, it seems much too narrow for the old stream. There was apparently an old divide at the bend of the present stream 3 or 4 miles north of Massillon, the valley being narrow and having a rock floor at slight depth. It seems not unlikely that the old stream had a westward discharge from Massillon along a depression utilized by the Pittsburg, Fort Wayne and Chicago Railroad, between Massillon and Orrville. It would there connect with the old Mohican Valley, which, as indicated above (p. 164), probably discharged northeastward to the old Cuyahoga. The thought that this may have been the line of discharge for the old Upper Tuscarawas did not occur to the writer while in the field, and too little attention was given the valley to justify an opinion. While it is a somewhat indirect course, that may not be a serious objection. So little is known concerning the district east of the Tuscarawas that it is impossible either to suggest an alternative line of discharge or to rule it out. The old line may be found to have continued northward from the vicinity of Massillon on the east side of the present stream past Turkeyfoot Lake, which, apparently, lies in an old valley, and to have come to the Tuscarawas again a short distance above New Portage. It would there connect with an old valley coming in from the

southwest and pass northward through Copley Marsh to the old Cuyahoga, a few miles northwest of Akron.

These courses are suggested on the assumption that the old line of discharge passed northward to Massillon; but as noted above there is a possibility that it led eastward to Canton. In that case it is not certain that the discharge was into the Cuyahoga. It may prove to have been northeastward to the Mahoning at Alliance and thence northward into the Grand River Basin. It seems, however, quite as probable that the discharge would have been northward from Canton past Turkeyfoot Lake and Copley Marsh to the Cuyahoga. Notwithstanding this uncertainty concerning the course of discharge, there is no question that the old Upper Tuscarawas was tributary to the Lake Erie Basin.

This northward-flowing system apparently embraced the greater part of Sugar Creek drainage basin and all the eastern tributaries of the Tuscarawas from One Leg Creek northward to the source of the river, though these tributaries have had their drainage basins greatly modified. At the supposed old divide on Sugar Creek, near Strasburg, the valley becomes reduced to scarcely half the width of the portion above, though the narrowest part has a breadth of nearly one-fourth of a mile. The evidence for the former northward discharge of this creek is greatly strengthened by the presence of a broad, partially filled valley leading northward from the bend at Beach City to the Tuscarawas at Navarre, which is utilized by both the railway lines that pass through these villages. The possibility that the lower course of Sugar Creek was a line of interglacial discharge for the old Upper Tuscarawas was considered above.

It is probable that only the lower course of Nimishillen Creek was tributary to Sandy Creek, the old divide being 3 or 4 miles below Canton, where the valley becomes very narrow. As noted above, it is uncertain whether the headwater stream of this drainage system discharged westward past Richville through an abandoned valley to the old Tuscarawas at Navarre, or instead met the old Tuscarawas at Canton. The northern portion of this old drainage system is evidently not in harmony with preglacial lines. Whether the extent of the present system is about the same as the old system is not easy to determine because of the great body of drift in that region.

HOCKING RIVER.

THE PRESENT DRAINAGE.

The Hocking drainage basin lies southeast of the southern part of the basin drained by the Muskingum. It has its headwaters on the east side of the Scioto Basin, near Lancaster, and connects with the Ohio at Hockingport. The length of the main stream is scarcely 100 miles, and the area tributary to it is only 1,200 square miles.

The fall of the main stream is about 250 feet between Lancaster and the mouth, a distance of perhaps 90 miles. Of this fall about 100 feet is made in the first 25 miles. The headwater portion of the basin carries a drift filling of 200 to 300 feet, but the middle and lower portions have but a moderate filling. They lie outside the glacial boundary, and have received a train of gravel and sand which was carried down toward the Ohio, and which graded up the valley to a level 75 to 100 feet above the present stream. The stream has carried away much of this gravel and sand, leaving only narrow strips of it as terraces on the borders of the valley and a small filling beneath the stream bed.

CHANGES IN THE HEADWATER PORTION.

There is no doubt that the headwater portion of Hocking River, as far down as the glacial boundary, and also nearly all the tributary drainage within the glacial boundary, formerly discharged northwestward into the westward outlet of the old Muskingum. This is indicated both by the slope of the rock floor and by abandoned valleys which connect the headwaters of the Hocking and its tributaries with the portion of the Scioto Basin traversed by the old Muskingum. The rock floor is shown by numerous gas borings at Sugar Grove to be about 650 feet above tide, while at Lancaster, 7 miles up the present valley, it is only about 600 feet, and at Hadley Junction, near which it connected with the old Muskingum, 550 feet. The valley from Sugar Grove to Lancaster is nearly a mile in average width, and becomes still wider as it opens into the Scioto Basin northwest of Lancaster. Yet the bordering uplands near Sugar Grove are higher than in any part of the Hocking drainage basin below that village, the highest points being above 1,200 feet, or nearly 600 feet above the rock floor of the valley.

Within 8 or 10 miles below Sugar Grove the uplands fall to about 1,050 feet. Within 3 miles the valley narrows to scarcely one-third its width

at Sugar Grove, or about one-fourth of a mile; it continues narrow for the next 5 miles, and below it is irregular and varies in width from one-fourth mile up to nearly a mile. The level of the rock floor in the narrow part below Sugar Grove, as shown by gas borings, is about the same as at that village, 650 feet, but farther down it appears to descend with the present stream. From the features just noted it seems probable that the old divide stood within a few miles southeast of Sugar Grove, but its precise position may be difficult to determine.

Beginning a short distance below Sugar Grove there are shelves along the borders of the valley at a height of 50 to 75 feet above the stream, or about 800 feet above tide; these seem to be remnants of an old gradation plain. By means of these rock shelves it may be possible to determine the condition of the old divide, but this has not as yet been done. It is still to be determined whether the portion of the Hocking Valley below this divide belonged to a single or to two or more distinct old drainage systems.

Upon turning to the tributaries of this headwater portion of Hocking River we find important changes. Clear Creek now drains a district eastward into the Hocking that was in large part drained westward into the Scioto Basin. The old divide between the westward-flowing stream and a much smaller stream flowing eastward into the Hocking is found about 4 miles from the mouth of the creek. The creek here passes through a gorge only 100 to 150 yards in width, or but a small fraction of its width near its present headwater portion. Above this gorge the tributaries of the creek point westward, while in the portion below they point eastward. The bluffs at this gorge rise abruptly more than 100 feet, and it is probable that the pass or col stood nearly as high as this abrupt part. This old divide is very near the glacial boundary, but a terrace of glacial gravel appears farther down the valley, at an altitude about 100 feet above the stream bed. This gravel is apparently of Illinoian age; this being the case, the stream was thrown across this divide as early as that ice invasion.

Changes of drainage on Rush Creek, the largest eastern tributary of this headwater portion of the Hocking, have been noted both by Tight and the writer. An abandoned valley, forming the old line of discharge from Bremen to Lancaster, was examined by the writer in 1890, and the cause for abandonment referred to great accumulations of drift immediately below Bremen. The position of the old divide crossed by the stream

in its present course south of Bremen was not determined. Tight examined this drainage basin in 1896 and located the old divide about 6 miles below Bremen. He also independently reached the conclusion that the stream formerly discharged westward from Bremen to Lancaster through the partially filled valley noted by the writer. This change of drainage has been discussed quite fully by Tight, and his description is accompanied by photographs of the abandoned valley and of the old divide.[1] Through a misinterpretation of the maps of that region, he has placed the old divide at the line of Fairfield and Hocking counties. Its position is really 2 miles below the county line, in section 10, Marion Township, Hocking County, where the photograph of the old divide was taken which appears in the paper referred to. At this old divide a ledge of rocks extends out fully halfway across the valley, reducing the width of the channel to scarcely 200 yards. This remnant of the col probably stands nearly as high as the old divide, and shows it to have been scarcely 50 feet above the present stream. The valley was filled with glacial deposits to a higher level than this remnant of the divide, for it is coated with gravel to a depth of several feet. The glacial boundary apparently follows somewhat closely the north side of Rush Creek from this old divide westward to its mouth at Sugar Grove. East from the old divide the drift border lies farther south than the stream, except in the extreme headwaters east of Junction City.

A peculiar change of drainage is found at Sugar Grove, near the mouth of Rush Creek. There are two broad channels opening out from Rush Creek Valley into the Hocking just above its mouth, which stand less than 50 feet above the stream, and yet are not utilized by the stream. Instead, the creek has turned away from both of them and cut a narrow gorge across a rock point on the east side of the valley. The point thus cut off rises nearly 100 feet above the level of these broad valleys, but the stream probably found a notch or depression back of it at a somewhat lower level. It seems necessary to suppose that both of these broad valleys were at one time filled sufficiently to cause the stream to select its present course. Yet it is difficult to account for the removal of the obstruction unless, perchance, the ice sheet was the obstruction.

The occurrence of two broad channels is also a puzzling feature. They do not appear to be in the natural position for an oxbow channel of

[1] Bull. Denison Univ., Vol. IX, Pt. II, 1897, pp. 33–37, Pls. D, E, F, and IV.

either the old north-flowing Hocking or the lower course of Rush Creek. Each is about as broad as the valley of Rush Creek above the point of separation from the latter, being nearly one-half mile in width, but they are decidedly narrower than the Hocking Valley. They seem too broad to have been excavated by an interglacial stream, and it appears more probable that the double channel is a preglacial feature.

A slight change in one of the eastern tributaries of Rush Creek, between the point where it leaves the old valley near Bremen and the old divide, should be mentioned. This tributary enters Rush Creek within a mile inside the glacial boundary, yet its lower course was so greatly obstructed by drift deposits that it has cut a new channel across a rock point south of the old channel.

The North Fork of Rush Creek enters the main creek through a rock gorge between Rushville and Bremen. The headwater portion apparently discharged westward near the line of the Ohio Central Railway, leaving the present valley about 2 miles above Rushville. The course is so greatly concealed by accumulations of drift that it can be only approximately determined.

RACCOON CREEK.

Passing over a few small northern tributaries of the Ohio below the mouth of Hocking River we come to the valley of Raccoon Creek. The sources of this creek are in western Athens and southern Hocking counties, on the immediate border of the Hocking Valley. One branch heads near the line of Athens and Hocking County within 1½ miles of the Hocking River and branches farther west are but 4 to 6 miles back from the river. The divide at the head of these tributaries is a prominent sandstone ridge with an elevation 200 to 300 feet above the Hocking Valley or 900 to 1,000 feet above tide. The heads of these tributaries are in valleys 100 to 200 feet below the crest of the dividing ridge, or about 800 feet above tide. In the middle part of this drainage basin there are remarkable variations in the valley contours, the streams being partly in low lands which have the appearance of being old lines of drainage, and partly in narrow valleys, with abrupt bluffs, which have the appearance of being newly opened channels. The writer did not give these features sufficient attention to warrant an interpretation. They are, however, under investigation by Tight.

SYMMES CREEK.

Immediately west of the lower end of the Raccoon drainage basin is the basin of Symmes Creek. The stream heads a short distance southeast of Jackson and has a general southward course to the Ohio, which it enters opposite the city of Huntington, W. Va. An inspection of this drainage system suggests a northward discharge for the entire system except a section a few miles in length in the lower course. The writer was able to trace out a series of valleys connecting the two headwater forks in southeastern Jackson County with the South Fork of Salt Creek. Grass Fork crosses an old divide within a mile north of the Jackson-Gallia county line. Its old line of discharge appears to have been in the reverse of the present course to the line of the Cincinnati, Hamilton and Dayton Railroad and thence westward past Clay, Vaughn, and Camba into Salt Creek. The region now drained by Black Fork appears to have discharged in part along the line of the railway just named from Gallia Furnace northward. The headwater portion of the creek may have discharged past Oak Hill, joining the other branch and Grass Fork at the swamp east of Clay. The present stream appears to have crossed an old divide in the vicinity of the county line a short distance east of Gallia Furnace.

Tight reports the discovery of an old divide south of Aid about 15 miles from the mouth of the creek. The portion of the drainage basin between this divide and the one near Gallia Furnace may have found an eastward discharge into Raccoon Creek, passing near the village of Patriot; the divide there between Symmes Creek and Raccoon Creek is exceptionally low.

LITTLE SCIOTO RIVER.

This small stream drains the southern end of the abandoned part of the old Kanawha channel in southwestern Jackson, southeastern Pike, and eastern Scioto counties, Ohio. It is singularly out of harmony with the old channel, as may be seen by reference to the sketch map (fig. 3, p. 101.) The east or Brushy Fork heads on the northeast border of the old channel about 3 miles north of Glade and takes a southward course, entering the channel at Glade and following it for about 6 miles. The stream then leaves the old channel near the line of Jackson and Scioto counties, and utilizes the channel of a little tributary. It is joined by Flat Fork, which leads eastward from California along the old channel, but which turns south

through a narrow rock-bound valley to enter Brushy Fork. The stream then follows the valley of this small tributary to its former head, 3 or 4 miles south of the county line. It then crosses an old divide into the valley of a larger stream coming in from near Mabees that discharged southwestward into the old Kanawha. It follows this valley down to the junction with Rocky Fork near Wallace Mills. The old valley of this tributary probably discharged westward from Wallace Mills to the old Kanawha along Rocky Fork (reversed), though possibly it continued down the line of the present stream and entered the old Kanawha channel near Harrison Mills. The distance to the old channel of the Kanawha, by either route, is only two miles from Wallace Mills. From Harrison Mills the Little Scioto River occupies the old channel nearly to the present Ohio. It, however, cuts off a rock point west of the old channel, just before entering the present Ohio.

Rocky Fork rises in the uplands west of the old Kanawha channel in southeastern Pike County, and follows that channel southward for several miles before turning east to join Brushy Fork. In leaving the old channel it seems to have disregarded the most favorable line of discharge.

The only cause for these incursions of the present drainage into the hills which has suggested itself to the writer is found in the large amount of filling which the old channel received, there being in places a depth of 60 feet of silt on the old rock floor. This amount of filling was perhaps sufficient to raise the drainage lines above the level of low divides among neighboring hills to the east and thus bring about the singular system of drainage presented by the Little Scioto and its tributaries. It is, however, somewhat doubtful if this silt filling caused all the changes, and they may prove to be independent of it.

SCIOTO RIVER.

The Scioto is the chief drainage system of central and southern Ohio. The main stream has a length of about 210 miles, and with its tributaries drains an area of 6,400 square miles. Its source is in eastern Auglaize County, and its mouth at Portsmouth, Ohio.

The region drained by the Scioto and its tributaries has undergone a series of changes of peculiar interest, some of which have been outlined in the discussion of the Ohio and Muskingum drainage basins. The present

system presents very few lines which are identical in extent and direction of drainage with the old system; indeed a large part is quite independent of the old system.

THE HEADWATER PORTION.

In the northern portion of the present system from the source down to the glacial boundary near Chillicothe the extent and the direction of discharge for the main stream and its tributaries are determined chiefly by the slope of the great Scioto Basin, the drift filling being so great as to nearly conceal the lines of preglacial drainage. This basin slopes from the eastern and western borders toward a north-to-south axis, while the axis itself has a decided southward slope. Moraines govern the courses of drainage only to a limited extent.

The Scioto itself leads down from the western rim to the axis of the basin in an eastward course, which is governed by a moraine lying on the north side of the river. It is met near Marion by a small northeastern tributary, Little Scioto River,[1] whose course is along the south border of the eastward continuation of the same moraine. The united stream then takes a southward course, but flows a little to the west of the axis of the basin as far as Columbus. In this portion the axis of the basin is more nearly followed by the Olentangy River, which for a distance of about 40 miles lies only 4 to 8 miles east of the Scioto. The two rivers become united at Columbus, where the Scioto makes an eastward turn to receive the Olentangy. From Columbus to Chillicothe the Scioto follows nearly the axis of the basin.

The Scioto receives three western tributaries above Columbus—Rush Creek, Bokes Creek, and Mill Creek. Each of these, like the main stream, rises on the elevated western rim of the basin. The courses of these tributaries are governed to some extent by morainic ridges, there being a ridge between Mill Creek and Bokes Creek, and another along a part of the north border of Rush Creek. Below Columbus three large western tributaries—Darby Creek, Deer Creek, and Paint Creek—are received. Darby Creek flows eastward from the western rim of the Scioto Basin along the south border of a morainic ridge to within a few miles of the Scioto. It there turns southward and joins the Scioto near Circleville. Its chief

[1] This stream must be distinguished from a tributary of the Ohio of the same name which, as above described, enters the Ohio a few miles east of the mouth of the Scioto.

tributary, Little Darby Creek, also heads in the elevated western rim of the Scioto Basin. Deer Creek heads in the western rim of the Scioto Basin and drains a narrow strip on the southwest border of the Darby Creek drainage basin, entering the Scioto about midway between Circleville and Chillicothe. Paint Creek with its several forks drains the southwestern part of the Scioto Basin and enters the Scioto at Chillicothe. As shown on Pls. II and XIII, the courses of several of its forks are governed largely by moraines.

The Scioto receives no eastern tributaries of importance above the mouth of the Olentangy River. The northeastern part of the Scioto Basin is drained by three south-flowing streams—Olentangy River, Alum Creek and Walnut Creek—each of which has a drainage basin but 5 to 10 miles in width. With the exception of the headwater portion of Walnut Creek, which is kept in a southward course by a moraine, these streams show little regard for morainic ridges. Their courses are in the direction of the most rapid slope of the basin. The Olentangy River, as above noted, enters the Scioto at Columbus, Alum Creek enters Walnut Creek a short distance south of Columbus, and the united stream enters the Scioto near Lockbourne, a few miles farther south. Just before entering the Scioto it is joined by Little Walnut Creek, a stream which rises near the Licking reservoir and, as above noted, follows nearly the line of the old westward outlet of the Muskingum down to the Scioto.

The portion of the Scioto drainage basin just described lies within the limits of the Scioto glacial lobe, which occupied the region as late as the Wisconsin stage of glaciation. The valleys are nearly all postglacial and are shallow and narrow, the depth seldom reaching 50 feet, while the width is commonly less than one-fourth of a mile. In places the valleys extend down through the drift into the rock, notably along the Scioto above Columbus and on the lower course of Alum Creek, but, as a rule, their beds are far above the level of the rock floor. It seems hazardous at present to attempt to restore the old systems of drainage in this northern part of the Scioto drainage area.

In the area drained by Paint Creek it is possible to trace preglacial valleys for some distance back from the Scioto. The main creek from Bainbridge eastward nearly to Chillicothe occupies a preglacial valley about a mile in width and fully 300 feet in depth. Before joining the Scioto,

however, it crosses a rock point in the old south bluff, as indicated by Orton.[1] The old drainage system, of which this valley is the lower course, probably drained an area of several hundred square miles, but as yet only a few of the old tributary lines have been traced.

It was noted several years ago by H. W. Overman, county surveyor of Pike County, that the headwater portion of Brush Creek above Fort Hill formerly discharged to the preglacial valley of Paint Creek at Bainbridge.[2] This interpretation was independently reached by the writer in 1889, and by Tight and Fowke a few years later.[3] There is a well-defined though partially filled valley connecting it at the north with Paint Creek, while at the south, near Fort Hill, the present stream is cutting a gorge across a low pass in the old divide.

The region now drained by Rocky Fork, a branch of Paint Creek, appears to have been drained by a line farther north, whose valley is only partially filled. A few suggestions of the old courses of drainage were obtained in northern Highland County and in Fayette County, but they are scarcely complete enough to justify a mapping or full interpretation of the lines of discharge.

THE LOWER COURSE.

The Scioto Basin terminates on the south at the hills of Ross County, just above Chillicothe. The Scioto there enters a district in which the hills rise 400 to 500 feet above the stream, and flows in a valley but little more than a mile in average width. The evidence that this lower course of the Scioto has now a discharge in the reverse direction from that of the old system has been so fully presented in connection with the discussion of the Ohio that only this passing reference seems necessary.

WESTERN TRIBUTARIES SOUTH OF THE GLACIAL BOUNDARY.

South of the glacial boundary the western tributaries of the Scioto are all small, and all are following their old lines. The most important one is Scioto-Brush Creek which drains the northwestern part of Scioto County and the eastern border of Adams County. Sunfish Creek drains much of the western half of Pike County, while Camp Creek and Bear Creek drain

[1] Geology of Ohio, Vol. II, 1874, pp. 653–655.
[2] Ohio Archæological and Historical Quarterly, Vol. I, 1887–1888, pp. 260–264.
[3] Bull. Denison Univ., Vol. IX, Pt. I, 1895, pp. 15–34.

each a small strip between the two tributaries just mentioned. The lower courses of these tributaries have been filled to some extent with silt and slack-water material, as a result of the filling of the Scioto Valley with glacial gravel.

BEAVER CREEK.

There are two important eastern tributaries of the Scioto entering south of the glacial boundary, Beaver Creek and Salt Creek. Beaver Creek is very small, but is of importance, as it occupies the broad channel of the old Kanawha from near Glade westward to the vicinity of Pikeville (see fig. 3, p. 101). It leaves the old valley near Pikeville and cuts across a rock point on its south border, passing into the Scioto below, while the old valley connects with the Scioto at Waverly, 3 miles above Pikeville. The silt filling in the old valley has perhaps been sufficient to cause this deflection of the present drainage.

SALT CREEK.

Salt Creek embraces a widely branching drainage system, with an area of about 500 square miles, which connects with the Scioto near the glacial boundary, a short distance below Chillicothe. There are really three drainage basins, which become united at the east border of the Scioto Valley and have a common line of discharge across the Scioto bottoms into the river. These are known as North Fork, Middle Fork, and South Fork of Salt Creek. North Fork drains the southwestern third of Hocking County and adjacent portions of Fairfield, Pickaway, Ross, and Vinton counties, its line of discharge being southeastward from Fairfield County across the eastern edge of Pickaway into Hocking County, and thence west of south across western Vinton and eastern Ross County. Middle Fork drains a much smaller area, lying in western Vinton and northern Jackson counties. South Fork drains about half of Jackson County northwestward through southeastern Ross County, and includes a few square miles of eastern Pike County.

That the North Fork of Salt Creek has been greatly enlarged by headwater accessions is so evident that several residents of the region who have no knowledge of geology have made a clear interpretation of the changes of drainage. They have noted a troughlike depression leading from near the head of the North Fork, in Pickaway County, westward up Plum Run, and thence onward across a marshy divide to Scipio Creek, and down that creek to the Scioto. This depression is a mile or more in width, and

is filled for a great depth with drift. They have also correctly placed the old divide at "the narrows," just above the line of Hocking and Vinton counties. The stream follows the broad valley southeastward past Adelphi and Haynes to the mouth of Queer Creek. It there turns southward into a much narrower valley which soon contracts to a width but little greater than the stream, showing clearly the position of the old divide. After passing the old divide the valley gradually widens as the old southward-flowing drainage is entered.

An oil boring recently made in the middle of this valley near the mouth of Queer Creek shows the rock floor to be only 35 feet below the present stream. The stream is estimated to be not far from 650 feet above tide at that point, making the rock floor fully 600 feet. This is sufficiently low to fit in well with the altitudes of the valley floors in the midst of the Scioto Basin, which are found to be not far from 550 feet above tide.

Probably the drainage along the line of the old channel from Adelphi to the Scioto was somewhat different from the present, for the tributary valleys have usually been completely concealed by drift. Laurel Creek, which enters at Adelphi, cuts off a rock point near its mouth. As a result of this filling it enters the stream a short distance east of the old mouth. At this place its valley is narrowed to scarcely one-eighth the width of the old valley.

The portion of the North Fork south of the old divide lies outside the glacial boundary, and it seems to have suffered no change aside from that of the accession above described.

The Middle Fork of Salt Creek lies outside the glacial boundary and apparently drains all of its old drainage basin. Only the lower course was examined by the writer, and this has a valley but 60 to 100 rods wide, which seems a natural width for a drainage basin of this size.

The South Fork of Salt Creek has suffered some reduction in the size of its drainage basin. It formerly received the headwater portion of Symmes Creek, as indicated in the discussion of that stream. The present divide at Camba is in a valley which opens northward and carries a silt filling of considerable depth. This silt is calcareous, a feature which indicates that it was derived from the glacial waters, for this is a sandstone region. The valley seems to have been ponded with water to such a height that an outlet was found across a low divide at its head. The amount of glacial

water passing through this valley was apparently very great, for it left a silt deposit nearly 100 feet in depth.

This stream has a valley 80 to 120 rods in width from a point near the present divide at Camba northward to the junction with Buckeye Creek, 2 miles below Jackson. It there enters the Logan conglomerate and becomes narrowed abruptly to a width of less than 200 yards. It continues narrow nearly to its junction with Middle and North forks. This constriction does not appear to mark an old divide, but on the contrary seems to be due entirely to the great resistance of the conglomerate to erosion.

LITTLE MIAMI RIVER.

Little Miami River, which enters the Ohio just above Cincinnati, is the first large northern tributary below the Scioto, yet the distance between the mouths of the two streams is more than 100 miles. The source of the stream is a few miles southeast of Springfield, Ohio, and the course is west of south to the Ohio. The length of the stream is about 100 miles and the drainage area probably 1,850 square miles. The East Fork, which is a nearly independent drainage basin, rises in southeastern Clinton County, a few miles east of Wilmington, and enters the main stream about 10 miles above its mouth. Two other important eastern tributaries are Todds Fork, entering at Morrow, and Cæsars Creek, entering near Waynesville. There are no large western tributaries.

RATE OF FALL.

The source of the main stream and also that of East Fork are at an altitude of about 1,150 feet above tide, while the mouth is less than 450 feet. The fall is therefore rapid, that of the main stream averaging about 7 feet per mile, while that of the East Fork is fully twice as rapid. In the 35 miles from its source to a point opposite Xenia the fall of the main stream is nearly 400 feet, but in the next 35 miles, to Morrow, it is about 130 feet, or only one-third as rapid as the headwater portion. In the lower 30 miles the fall is about 180 feet, it being more rapid than in the middle portion.

CHANGES IN DRAINAGE.

The headwater portions, both of the main stream and of its tributaries, flow in shallow valleys 50 to 60 feet or less in depth, but from a few miles below Xenia to the mouth the valley is 200 to 300 feet or more in depth.

This deep portion apparently unites at least three old valleys which formerly discharged westward into the Great Miami Basin, as indicated below. In the headwater portion the streams are in places entirely independent of the old drainage lines, and there is evidently but little harmony between the present drainage system and the old one.

A hint concerning the old discharge of a part of the Little Miami Basin into the Great Miami is given by Orton in his map of Warren County, Ohio, though his description leaves the direction of discharge uncertain.[1] A drift-filled lowland departs from the Little Miami at Deerfield (South Lebanon) and passes northwestward to the Great Miami just below Middletown. It appears to have been a line of discharge for the middle part of the Little Miami into the Great Miami drainage basin. The only element of uncertainty is the report that wells in the lowland near the present divide have in some instances entered rock at higher levels than those in parts of the lowland nearer Little Miami and Great Miami rivers. These, however, do not rule out the presence of a channel at a little distance from the wells.[2]

In the Little Miami near Fort Ancient, a few miles above Deerfield, there is a notable constriction, which was apparently the site of an old divide. Another divide was probably situated below Deerfield, near the south line of Warren County. Between these divides there appears to have been a drainage system which embraced most of the area now drained by Todds Fork, as well as a small section of the Little Miami which led northwestward through the lowland above mentioned to the Great Miami.

The headwater portion of the Little Miami, down at least to the vicinity of Xenia, appears to have connected with the Great Miami through the lower course of Mad River. There is an open channel between the two rivers that is now drained to the Little Miami by Beaver Creek. This evidently was used as a southward discharge for glacial waters, but it seems probable that earlier it may have constituted a line of northward discharge from the headwater portion of the Little Miami into Mad River. Possibly the course was not coincident with the open channel, for on the border of the channel there is a morainic belt that greatly disguises the old features.

The East Fork is in an old valley in its lower course, but the headwater portions are largely independent of the old drainage lines. It seems probable that a part of the region now drained southward to the Ohio by Brush

[1] Geology of Ohio, Vol. III, 1878, p. 382.

[2] Compare Bownocker: Ohio Acad. Sci., Special Paper No. 3, 1900, pp. 32-45.

Creek once discharged westward through the lower course of the East Fork of Little Miami. This may have embraced the entire portion between the old divide crossed by Brush Creek near Fort Hill and another supposed divide located by Tight east of West Union.[1] The amount of drift is so great in the region between Brush Creek and the East Fork that few surface indications of the courses of the old drainage lines can be found.

GREAT MIAMI RIVER.

THE PRESENT SYSTEM.

The Great Miami is the main drainage system of western Ohio. Near its mouth it receives Whitewater River, which drains an area of about 1,500 square miles in southeastern Indiana. The Whitewater, however, is here treated as a separate system. Exclusive of the Whitewater, the Great Miami has a drainage area of nearly 4,000 square miles, or about one-tenth of the State of Ohio. Its headwaters are in the divide which separates the Mississippi from the St. Lawrence drainage. It drains the greater part of the Cincinnati arch from that divide south to the Ohio River.

The main stream has its headwaters about 1,000 feet above tide. Its main eastern tributary, Mad River, heads in a more elevated tract in Logan County, whose highest points exceed 1,500 feet. The source of Mad River, however, is in a valley-like depression, standing about 1,300 feet above tide, which also constitutes the source of Rush Creek, a western tributary of the Scioto. Whitewater River, the main western tributary, heads in the most elevated part of Indiana, at an altitude of nearly 1,200 feet.

The main stream and its headwater tributaries, as far down as the vicinity of Dayton, flow in comparatively shallow postglacial valleys, with courses largely independent of the old drainage lines, the amount of drift being so great as to completely fill the old valleys. Mad River, it is true, occupies a broad trough-like valley throughout much of its course, but on its borders there are moraines which cause most of the relief, the immediate bluffs being generally but 20 to 30 feet in height. Furthermore, its course seems to be independent of the old drainage

Below Dayton the Miami and some of its tributaries occupy old valleys which were only partially filled with glacial deposits. The work of the present streams is mainly the reexcavation of the valleys. In this

[1] Communicated to the writer.

work they have fallen far short of reaching the old rock floors, which lie 100 to 200 feet below their beds. The depth of this reexcavation is but 50 to 100 feet, and the width but a small fraction of that of the old valleys, seldom so much as one-fourth as great. The contrast between the southern and northern portions of this drainage basin, therefore, is not found in the work of the present streams, but is due to the less complete concealment of the old drainage lines by glacial deposits.

CHANGES IN DRAINAGE.

J. A. Bownocker has recently presented a partial restoration of the old drainage in the headwater portion of this drainage basin.[1] The course of the old drainage line has been made known by borings for oil and gas, which are numerous in that region. It is not perceptible on the surface except for a few miles in eastern Indiana, where a sag or shallow valley marks its course. The present systems of drainage show a nearly complete disregard of the old drainage lines. The course of the old line, as noted by Bownocker, is northwestward from near the Great Miami, in Shelby County, Ohio, past Anna and the Grand reservoir, to Rockford, Ohio, on the St. Marys River. It there turns southwestward, crosses the Wabash River at Geneva, Ind., and continues past Pennville into Blackford County, Ind., where the tracing was discontinued. The length of the line thus traced is about 90 miles. This old line received a southern tributary at the Grand reservoir, with a head probably near Xenia, but no other well-defined tributary was recognized between that point and Blackford County. Two channels were there found, one of which leads northward and the other westward, but the data are insufficient to show which was the main channel.

The width of this old valley appears to be about 1 mile, with a possible range from three-fourths of a mile to $1\frac{1}{2}$ miles. The filling of drift is found to range from 320 feet up to 514 feet, the variation being principally due to the different altitudes of the present surface. The rock floor is not far from 500 feet above tide in the eastern portion, but falls to scarcely more than 400 feet in eastern Indiana. It is markedly higher than the Ohio at the mouth of the Great Miami, whose rock floor is less than 400 feet above tide. The course seems to show that it was a tributary of the

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[1] A deep preglacial channel in western Ohio and eastern Indiana, by J. A. Bownocker: Am. Geologist, Vol. XXIII, 1899, pp. 178–182. Also Ohio Acad. Sci., Special Papers No. 3, pp. 32–45, with map.

old Wabash system. The size of the valley indicates that it drained at most only a few counties of western Ohio. The old drainage of a considerable part of the region now drained by the Great Miami appears to have been independent of this line. It is probable that the old drainage south from the latitude of Dayton followed nearly the course of the present lines to the Ohio. As already indicated, the old Ohio was entered by the Great Miami near Hamilton. The latter stream makes slight departures from the line of the old Ohio below Hamilton, the old Ohio channel being in part farther west than the Great Miami.

WHITEWATER RIVER.

OUTLINE OF THE PRESENT SYSTEM.

Several streams which have their sources in a moraine in southern Randolph County, Ind., and southwestern Darke County, Ohio, converge southward to form the Whitewater River. These are known as West Fork, Martindale Fork, Greens Fork, Nolands Fork, and East Fork. The first four become united between Cambridge and Connersville to form the West Whitewater; the fifth (East Fork) unites with the West Whitewater at Brookville. The area of the entire Whitewater drainage basin is about 1,500 square miles.

The headwater portions for 15 to 20 miles are flowing in channels cut in the drift. The East Fork then, near Richmond, enters the rock, and has carved its course partly in rock from that point to Brookville. The West Fork encounters rock at only a few points. Below Connersville it is in a partially filled preglacial valley, with broad bottom and elevated uplands on either side.

The West Fork, with its headwaters, constituted an important line of drainage for the waters from the ice sheet at the time the moraine above referred to was forming, and probably also at earlier stages in the Glacial epoch. It is in consequence a gravel-filled valley, and the work of the present stream has been merely a removal of a small portion of these gravel deposits. Above Cambridge it has cut scarcely 20 feet into these deposits. The depth gradually increases southward to Brookville. At Brookville and below that city it has formed a channel 60 to 75 feet in depth. The surface of the gravel deposits in the headwater portion above Cambridge has a southward descent of nearly 10 feet per mile. From Cambridge to the

State line at Harrison, Ohio, a distance of scarcely 70 miles, the gravel deposits have a descent of 350 feet, or fully 5 feet per mile. The present stream, having cut about 50 feet deeper into the gravel deposits at Harrison than at Cambridge, has a fall of nearly 6 feet per mile.

CHANGES IN DRAINAGE.

Possibly the northern part of this drainage basin, like that of the Great Miami, was formerly drained westward toward the Wabash, for channels of great depth are occasionally encountered by oil and gas borings in the district to the west. There is, however, some doubt as to such a drainage course, for the size of the lower end of the Whitewater Valley seems to require a drainage area nearly as large as the present, the width of the valley being about a mile and the depth 500 feet. Furthermore, the large valley occupied by the southern part apparently drained, as now, to the Ohio. The rock floor at Brookville is shown by gas borings to be about 490 feet above tide. At a boring 5 miles below Brookville it is only 450 feet; while at the mouth of the stream, 18 miles farther down, it is less than 400 feet.

TRIBUTARIES OF THE OHIO IN INDIANA.

Between the mouth of the Great Miami at the east line and the mouth of the Wabash at the west line of Indiana there are no large northern tributaries of the Ohio. This is owing to the fact that the drainage of the greater part of Indiana is toward the Wabash, instead of directly to the Ohio. A tributary of the Muscatatuck heads within 2 miles of the Ohio near Madison, Ind., and yet leads westward to the East White and thence across the State to the Wabash. Nearly all of the tributaries in southern Indiana head within the limits of the counties that border the river, and consequently have a length of less than 30 miles. Only two, Blue River and Laughery Creek, have greater length.

In southwestern Indiana, where the altitude is low, the streams have very little fall, and are occupying broad, shallow valleys, which are not infrequently filled to depths of 50 feet or more with marshy alluvium. In the more elevated tracts, whose western border is crossed by the Ohio between Cannelton and Rockport, Ind., the streams present valleys cut to a correspondingly greater depth. Their bottoms are narrow and well drained, the

fall of the streams being adequate to give rapid escape for the surplus rainfall. The streams make a descent of 300 to 500 feet, in some cases, within a distance of 10 to 20 miles. Notwithstanding this descent there are very few waterfalls. The only notable ones occur in southeastern Indiana, where the drift deposits have obstructed the old valleys and led to the development of new lines of drainage. In the unglaciated portion of southern Indiana there are but few rock rapids, and, so far as the writer is aware, no waterfalls. The gradients of streams, though steep, show a gradual lessening in rate of descent in passing from source to mouth and a general disregard for hardness of strata, such as results only from maturing of a drainage system. The rapid rate of descent is not favorable to the development of broad flood plains, yet there is usually a flood plain having several times the breadth of the stream bed. In this respect the tributaries, as noted above, have accomplished more work in proportion to their size than the Ohio. It is difficult to realize that the broad valleys of small streams in southwestern Indiana were begun at no earlier date than the narrow valleys of the higher district, yet such was probably the case.

WABASH RIVER SYSTEM.

The drainage basin of the Wabash embraces an area of about 33,000 square miles, distributed as follows: In Ohio, 400 square miles; in Indiana, 24,350 square miles; in Illinois, 8,250 square miles. It drains, therefore, slightly more than two-thirds of Indiana, the area of the State being 35,910 square miles. Of the portion in Indiana, about one-half is embraced in the drainage area of the East White and West White rivers. By including these drainage areas with the Wabash the entire watershed has a nearly symmetrical, broadly ovate form. Not including the White River system, the Wabash watershed is an unsymmetrical, elongated tract, curving around White River.

Only a small part of the Wabash watershed lies outside the glacial boundary. The Wabash and West White rivers lie within that boundary for their entire length. The East White flows within the glacial boundary to western Jackson County, but from that point to western Martin County it is outside the drift. It enters the drift-covered district in its lower course near the corners of Martin, Davis, and Dubois counties, and remains within the glacial boundary from that point to its mouth. The greater part of

this system being within the limits of glaciation, and in a region where the drift coating is sufficiently thick to conceal more or less completely the preglacial valleys, it has been largely developed in interglacial and postglacial time. The lower courses of the Wabash, West White, and East White are, however, following nearly the preglacial lines.

WABASH RIVER.

The valley occupied by the Wabash River has not had a uniform development from source to mouth. In its upper part, from the source to Huntington, Ind., the valley has been formed chiefly by the present stream, and is a shallow and narrow trench. At Huntington the river enters the old outlet of Lake Maumee, a glacial lake that occupied part of the basin of Lake Erie. This outlet has a valley several times as large as that occupied by the Wabash above this point. It opened a new or postglacial line of drainage in its westward course across Indiana, except for a few miles in the vicinity of Lafayette, where it crosses or follows a preglacial valley for a few miles. It has been compelled to do considerable excavation in rock from Huntington down as far as Covington, and still carries rapids at several points. Below Covington the stream follows very nearly the line of a partially filled preglacial valley, and its work has been largely the removal of a portion of the glacial deposits left in that valley. It makes, however, some deflections into the edge of the uplands, cutting off points of the bluffs. At such places the channel is occasionally in process of excavating rock. The cause for these deflections is not in all cases clear, but it is probable that in the majority of cases the filling was such that the stream was free to pass across these points and thus take a more direct course than that of the old line around them. In some cases it is possible that the ice sheet may have had an influence in guiding the stream across projecting points beneath it or on its border.

The length of the valley occupied by the Wabash is about 450 miles; but the length of the stream is much greater, for the river in its lower course makes several oxbow curves within the valley. The source of the river is about 1,000 feet above tide, while its mouth at low water is but 311 feet. The average fall, if we estimate the stream to have a length of 500 miles, is therefore about 16½ inches per mile. The rate of descent is far from uniform, being much more rapid in the upper portion than in the

lower. There are also many rapids, separated by pools or sluggish portions of the stream. The elevation of the stream has been determined at many points, but in the absence of a careful measurement of its length the rate of fall is only approximately known. The portion of the river above the point where it enters the old lake outlet, estimated to have a length of 100 miles, has a fall of about 300 feet, or 3 feet per mile. Railway levels and canal surveys at the point where the river joins the old lake outlet show its elevation to be very nearly 700 feet above tide, the altitudes reported varying between 696 and 699 feet. The canal survey below Huntington shows a fall of 32 feet to the mouth of the Salamonie, a distance of about 15 miles, and a fall of 34 feet between the mouth of the Salamonie and the mouth of the Mississinawa, a distance of perhaps 20 miles. In the next 20 miles, to Logansport, there is a fall of 50 feet. From Logansport to Lafayette, a distance of about 50 miles, there is a fall of 77 feet. From Lafayette to Attica, a distance of 25 miles, the fall is but 19 feet, and from Attica to Covington, a distance of 20 miles, but 17 feet. From Covington to Terre Haute, a distance of about 55 miles, there is a fall of only 22 feet, this being the lowest gradient for so long a section found on the river. From Terre Haute to the mouth of White River an accurate survey by the United States Army engineers shows a fall of 71.18 feet in a distance of 122.55 miles, or about 8 inches per mile. In this distance there are 13 riffles, each but a fraction of a mile in length, which have a combined fall of 17.86 feet. These reduce the fall of the 120 miles not embraced in the riffles to 53.32 feet, or 5.33 inches per mile. The greatest fall at a riffle in this section of the Wabash is at Grand Rapids, just above the mouth of White River, where it amounts to 4.5 feet.[1] The fall from the mouth of the White is 65 feet in a distance of perhaps 90 miles by the windings of the stream.

[1] Thirteenth Ann. Rept. Geol. Surv. Indiana, 1883, pp. 69, 70.

The following table includes the data upon which the above statements are made:

Table of altitudes and distances along Wabash River.

Location.	Estimated distance.	Altitude (above tide).	Fall per mile.
	Miles.	*Feet.*	*Inches.*
Source	0.0	1,000.0	0.00
Huntington	100.0	699.0	36.00
Mouth of Salamonie River	15.0	667.0	25.56
Mouth of Mississinawa River	20.0	633.0	20.40
Logansport	20.0	583.0	30.00
Lafayette	50.0	506.0	18.48
Attica	25.0	487.0	9.12
Covington	20.0	470.0	10.20
Terre Haute	55.0	447.7	4.80
State line	14.6	440.6	5.80
Hutsonville, Ill	29.0	424.6	6.60
Vincennes	46.4	398.8	6.60
Mouth of White River	32.5	376.5	8.30
Grayville, Ill	28.0	365.0	5.00
Mouth of Little Wabash	46.0	323.0	11.00
Mouth of river	16.0	311.0	9.00

SALAMONIE RIVER.

Salamonie River enters the Wabash from the southeast a few miles above the city of Wabash. It has a length of about 75 miles. Its source is on the northern slope of the elevated limestone district of eastern Indiana, at an altitude of about 1,000 feet above tide. Throughout the greater part of its course the river follows a plain on the south border of the Salamonie moraine. Its descent is measured by the descent of the plain, except in the lower 40 miles, where it has deepened its channel to enter the old lake outlet. Sufficient time has not elapsed since the river began flowing for it to form a regular gradient. It can scarcely be said to have developed a valley except in the lower 40 miles, the bed of the stream in its upper course being seldom more than 20 to 25 feet below the bordering plain. The descent from Portland to Montpelier is less than 3 feet per mile, but in the 40 miles from Montpelier to the mouth the average descent is about 4 feet per mile.

MISSISSINAWA RIVER.

Mississinawa River, a southeastern tributary entering the Wabash near Peru, has a length of about 100 miles. Its source is in western Ohio, 10 or 12 miles beyond the State line, on the north slope of the elevated limestone district which occupies eastern Indiana and western Ohio. At its source the altitude is probably 1,100 feet above tide. In the 25 miles from its source to Ridgeville, Ind., the stream has a fall of about 5.5 feet per mile, descending with the plain which it follows on the south border of the Mississinawa moraine, and cutting but 15 to 30 feet into the plain. From Ridgeville to Marion, a distance of 50 miles, the rate of fall is but little more than 3 feet per mile. The stream in this distance has deepened its channel slightly, but at Marion is scarcely 50 feet below the bordering plain. Most of the work accomplished by the stream is in the section between Marion and the mouth, a distance of only 30 miles. Its fall in this section is about 5.5 feet per mile, or fully as great as in the headwaters. The depth of the channel increases from about 50 feet at Marion to fully 100 feet in the vicinity of its mouth. It is excavated mainly in drift, but at some points has extended a few feet into the underlying rock strata.

EEL RIVER.

Eel River, a northeastern tributary of the Wabash, entering at Logansport, has a length of about 85 miles. Its source is on the inner border of the great Erie-Saginaw interlobate moraine, a few miles north of Fort Wayne, at an elevation of about 850 feet above tide. The average fall of the stream is very nearly 3 feet per mile, the elevation of the mouth being 543 feet. The following table of distances and elevations is based upon Williams's list of altitudes, given in the Tenth report of the Indiana geological survey:

Altitudes along Eel River.

Location.	Distance from mouth.	Altitude (above tide).
	Miles.	*Feet.*
Source, about	85	850
Columbia City	70	816
Collamar	58	768
Liberty Mills	50	750
North Manchester	45	721
Eel River railroad bridge, in Miami County	30	688
Mouth, at Logansport	0	583

The headwater portion of this stream, like that of the Mississinawa and Salamonie, has a poorly developed channel and a sluggish current. It is only in the lower 25 or 30 miles that erosion of any consequence has occurred. Even here the valley scarcely exceeds 50 feet in depth.

TIPPECANOE RIVER.

Tippecanoe River is the main northern tributary of the Wabash within the State of Indiana. It has a length of about 125 miles, and drains a belt averaging perhaps 20 miles in width. Its source is in the midst of the great interlobate moraine of northeastern Indiana, at an elevation of nearly 1,000 feet above tide. It descends the northwest face of the moraine from southwestern Noble County into Kosciusko County, reaching a level 800 feet above tide north of Warsaw. It follows the north border of the moraine a few miles southwestward, to the point where the Saginaw and Erie moraines become differentiated. It then passes through a gap in the Saginaw moraine and enters a sandy plain formerly occupied by the waters of "old Lake Kankakee." After traversing this plain for about 60 miles, it leaves the old lake area near Monticello and passes through an Erie moraine which follows the northwest border of the Wabash River, and enters the Wabash from a narrow plain on the inner slope of this moraine.

Although bordered in places by elevated knolls and ridges in the upper portion of its course, it has no well-defined valley, nor has it excavated a valley of much depth in the old lake bottom. The main excavation occurs in the lower 30 miles of its course, and even here its channel is narrow and scarcely reaches 100 feet in depth. In this lower portion the rate of fall is about 3 feet per mile. The fall is less in the section traversing the old lake bottom, being about 150 feet between Rochester and Monticello, a distance of 60 miles. The great fall of the upper portion is chiefly made in short sections, connecting marshes whose levels become successively lower in passing down the slope of the moraine.

WEST WHITE RIVER.

The chief tributary of the Wabash is West White River, which enters it from the east at a point about 90 miles from the mouth. If we include with the West White its entire system of drainage, it will embrace about one-third of the State of Indiana, or an area about as great as that drained by the Wabash and its other tributaries within that State. The West

White proper, however, drains only about one-sixth of the State, the drainage basin of the East White, its principal tributary, being nearly as great as that of the main river.

The source of the West White is in Randolph County, near the east line of the State. The course of the stream is westward to Hamilton County, a distance of nearly 75 miles, where it turns abruptly southward and leads in a course somewhat west of south to the Wabash River.

The length of the valley of this stream is about 275 miles, but this does not represent the length of the stream, for in its lower part it winds greatly within its valley, adding perhaps another hundred miles to its length. The estimates given below are, however, based upon the length of the valley rather than that of the stream. They indicate the condition when the river is out of bank, as is occasionally the case in high-water stages.

At its source the stream has an elevation of not less than 1,175 feet, while at its mouth the elevation is but 375 feet above tide. It has, therefore, an average fall of nearly 3 feet per mile, or more than double the average fall of the Wabash River. In its upper 15 miles the fall is estimated to be about 8 feet per mile; in the next 25 miles, about 6 feet per mile, and in the succeeding 20 miles, about 5 feet per mile, making a fall of 375 feet in a distance of 60 miles, or to a point near the city of Anderson. Below Anderson the fall for the 50 miles to Indianapolis is nearly $2\frac{1}{2}$ feet per mile. Below Indianapolis for about 30 miles the fall exceeds 3 feet per mile. In the remaining 130 miles of its course there is a fall of but 185 feet, or slightly less than $1\frac{1}{2}$ feet per mile.

Aside from its main tributary, East White River, there are but two tributaries of White River which exceed 50 miles in length, namely, Fall Creek, an eastern tributary entering just above Indianapolis, and Eel River, a western tributary entering at Worthington, in northern Greene County.[1] Fall Creek has an elevation at its source of at least 1,000 feet and at its mouth of about 700 feet. Fully half of the 300 feet of descent is made in the upper 20 miles, leaving a fall of 150 feet for the lower 40 miles. It derives its name from a cascade about 10 feet in height in the sandstone at Pendleton. Eel River has a length of nearly 100 miles. Its east fork,

[1] This river should be distinguished from a stream of the same name entering the Wabash at Logansport.

known as Mill Creek, is about 40 miles in length, and its west fork, known as Walnut Creek, fully 50 miles. Below the junction of these forks the stream has a length of about 45 miles, if the minor windings of the channel are disregarded.

EAST WHITE RIVER.

This large tributary enters the West or main White River about 40 miles above its mouth. It drains the district immediately east of that drained by the main river and has an area nearly as great, there being about one-sixth of the State of Indiana tributary to it.

The headwater portion above Columbus, Ind., is usually known by the name of Blue River, the name East White being applied to the stream below its junction with Flat Rock Creek at that city. The name Driftwood is also applied to the lower portion of the river. Inasmuch as there is another stream within the State called Blue River, it is unfortunate that this name is applied to the headwater portion of East White River.

The upper half of the drainage basin of East White River lies within the glaciated districts of eastern and southeastern Indiana. The streams find their sources in the elevated Upper Silurian limestone belt, in the eastern part of the State, and descend rapidly westward to the Devonian shale area. The main stream leads through the western part of the drainage basin, and hence receives nearly all its tributaries from the east. The drainage system is, therefore, very unsymmetrical.

Although these headwater tributaries make a great descent in passing down to the basin of Devonian shale, they have carved very insignificant channels. The valleys are usually so shallow that their bridges may be seen for miles back from the borders of the streams. A portion of the Muscatatuck drainage system is, however, characterized by deeper channels, a feature which is probably attributable to the greater age of that system. It lies outside the limits of the newer, or Wisconsin, drift, while the principal tributaries of the East White farther north flow throughout most of their course within the limits of the newer drift sheet.

The northern tributaries, Blue River and Flat Rock Creek, have their sources in northeastern Henry County at an elevation of about 1,100 feet above tide. They make a descent of about 500 feet in the 100 miles from their source to the junction at Columbus, or an average fall of about 5 feet per mile. In the lower 35 miles of its course, from Shelbyville to Columbus,

Blue River has a fall of about $4\frac{1}{2}$ feet per mile, nearly as great as the fall of the headwater portion above Shelbyville. From Columbus to the mouth of the Muscatatuck, a distance of 55 miles, the average fall is very nearly 20 inches per mile. In the remaining 125 miles, where the stream is flowing in a preglacial valley, the fall is about 10 inches per mile. In this portion there are, however, occasional riffles and rapids in which a descent of several feet is made within a mile. The most conspicuous of these rapids is at Hindostan, where a fall of about 5 feet occurs. At this point the stream has cut off an old oxbow and is excavating the rock in the ridge encircled by the oxbow.

The Muscatatuck River in its lower 25 miles has very little fall compared with the neighboring portion of East White River. At the railway crossing south of Seymour the bed of the Muscatatuck is 40 feet lower than at the crossing on the East White immediately north of Seymour. The difference in gradient is due to a filling of the East White Valley by deposits of gravel at the Wisconsin ice invasion. As the Muscatatuck drainage system lies outside the limits of this later ice invasion or the reach of its waters, its valley remains unfilled. The fall on the lower 25 miles of the Muscatatuck is apparently not more than 10 feet, while on East White River, in the 25 miles above the mouth of the Muscatatuck, there is a fall of about 50 feet.

The portion of the East White River Valley lying within the unglaciated districts of southern Indiana is cut to a comparatively low gradient, notwithstanding the hardness of the rock formations through which its course is channeled. The valley at present is silted up to a height of perhaps 100 feet above the rock floor. The bluffs rise 200 to 300 feet or more above the present valley bottom, thus giving the preglacial valley a depth of 300 to 400 feet. If we consider this great depth and the hardness of the formation, the width of the valley, which is seldom less than one-third mile and probably averages more than one-half mile, is not surprisingly small. The valley of this stream, like that of the Ohio in the corresponding section, presents a series of oxbow curves, with very little straight channeling.

Within this unglaciated portion the East White receives one important northern tributary, Salt Creek. This stream has a length of about 60 miles from its headwaters, in Brown County, to its mouth, near Bedford, in Law-

rence County. It drains the greater part of the elevated district in Brown, Jackson, Monroe, and Lawrence counties. In its headwater portions, in Brown County, the valleys are cut to a depth of 300 and in places 500 feet below the level of the neighboring hills, and a dendritic system of drainage has been developed, which is strikingly in contrast with the irregular and unsymmetrical drainage systems of the streams within the drift-covered regions to the north and east. At its headwaters the valleys have been filled to a marked degree by deposits of sand and gravel made by streams issuing from the edge of the ice, which for a time overhung the northern portion of Brown County. The valley is apparently filled to nearly as great an extent as the portion of the East White with which it connects. Its rate of fall is more rapid than that of the East White, but is less rapid than that of some of the large streams of the glaciated district. The fall of the North Fork from Nashville, a few miles from its source, to the mouth of the stream is only about 150 feet, or scarcely more than 3 feet per mile.

Lost River, a tributary entering East White River from the east in southern Martin County, has a length of about 50 miles. This stream receives its name from the fact that it flows for a few miles in a subterranean passage in the St. Louis limestone. In times of freshet the stream can not be entirely absorbed by the subterranean channel, and it then flows on the surface in its former bed, which is now covered with a heavy forest.

PATOKA RIVER.

Patoka River, a distinct tributary of the Wabash, drains a narrow belt along the south border of the drainage basin of East White River. The stream has a length of over 100 miles, but its drainage basin nowhere exceeds 20 miles in width. Its source is in the hills of the Chester or Kaskaskia sandstone, in southern Orange County, at an altitude of about 800 feet. Its mouth is just below that of White River, at an elevation of 375 feet above tide. This drainage system is made up of three small drainage systems, which were formerly distinct and discharged northwestward into the White and East White rivers. The upper system embraced the portion above Jasper, Ind., the old divide being at the northeast border of that village. The middle system embraced the portion between Jasper and Velpen, Ind., and the lower the part from Velpen down to the vicinity of Princeton. The old drainageway there turned north to White River, near

Hazelton, but the present stream continues westward across a rock point into the Wabash Valley. A map showing the changes which this drainage system has experienced, and also changes in smaller tributaries of the Wabash in southwestern Indiana, appears in the monograph on the Illinois Glacial Lobe.[1] The changes are there discussed in considerable detail.

WESTERN TRIBUTARIES OF THE WABASH IN ILLINOIS.

The western tributaries of the Wabash are all comparatively small. Those whose courses lie within the limits of the Wisconsin drift are not governed by the preglacial drainage, for the dritt has filled the region to a higher level than the old divides. But south from the border of the Wisconsin drift the courses of streams are governed to a large extent by the preglacial drainage lines. The few changes or departures from the old drainage are discussed in Monograph XXXVIII, as are also the influence of morainic ridges of Wisconsin age upon the course of the streams.

CAUSES FOR CHANGES IN DRAINAGE.

Of the several factors which are influential in causing changes of drainage, glaciation is known to have been widely operative in this region. Piracy seems to have been operative, at least to a limited extent, and possibly has had wide influence. In addition to these the influence of uplift or earth movements should perhaps be considered.

GLACIATION.

With the extension of the earliest glaciation into the lower courses of a northward-flowing stream there would have been a ponding of water in front of the ice field. This ponding would eventually reach a height at which discharge could take place over the rim of the drainage basin, and a new system of drainage would be inaugurated. With the advance of the ice field many streams would be thus affected, and in some cases the influence of the ponding might be felt at points many miles beyond the limits of the ice field. In the region under consideration streams which had been flowing from the Appalachian region northward into the basins now occupied by Lakes Erie and Ontario are likely to have experienced ponding in their lower courses before the ice field had encroached greatly on the basins of

[1] Mon. U. S. Geol. Survey Vol. XXXVIII, Pl. VIII.

these lakes. This would perhaps at first result in lakes that drained southwestward through the Maumee Basin to the Wabash. But with the advance of the ice field the lake basins would become filled, and ponding would extend southward toward the present Ohio. New lines of discharge would then be opened. This process of shifting to new lines might continue in parts of the region down to the culmination of the glaciation, but in other parts the final shifting may have taken place long before the ice field reached its extreme limits. A stream which suffered a late diversion should accomplish correspondingly less work than one that suffered an older diversion, so that by the amount of work the relative dates of diversion may be estimated.

The effect of glaciation in diverting streams would in some cases be restricted to the time when the ice field was present, there being a return to earlier courses upon the withdrawal of the ice. But in other cases the first ice invasion produced a permanent diversion of drainage. In each succeeding stage of glaciation the streams would be subject to disturbances similar to those produced by the earliest glaciation. This field is liable, therefore, to contain examples of diversion of various dates, from the first obstruction of the northward drainage by the encroachment of the ice field on the basins of the lower Great Lakes down to the close of the last glacial stage and the final disappearance of the ice from these basins. Instances of diversion and of control by glaciation or glacial features, illustrating the wide differences in date, will appear in the course of the discussion of the glacial features.

Turning to the Ohio, it will be found that the old Upper Ohio or Monongahela system was diverted to the present course at a date at least as early as the culmination of the earliest glaciation in the Upper Ohio region, a glaciation that was probably Kansan if not pre-Kansan. While a part of the change (in the portion between New Martinsville and Moundsville, W. Va.) appears to have been produced through piracy at an earlier date than the first glaciation, there seem to be no grounds for inferring that the great diversion of the old Monongahela from the northward to the southwestward line of discharge took place through piracy. On the contrary, the slope of the old gradation plain toward the Lake Erie Basin is so great that it seems scarcely possible for it to have been disturbed through piracy by the southwest system of drainage. It may be suggested that a

difference in the relative elevation of the Lake Erie Basin and the Ohio Basin has been produced, by which the slopes toward the Erie Basin have been greatly increased; but of this there is no specific evidence so far as the writer is aware. The available evidence seems to support the view that this diversion of the old Monongahela system to the Middle Ohio system took place as a result of the first glaciation, though it may have been brought about some time before the ice sheet had reached its farthest limits. This diversion seems to have been a permanent one; at least no evidence of a return to the Erie Basin after the earliest glaciation has been noted.

This earliest glaciation appears also to have thrown the several preglacial components of the Allegheny into their present course, and so far as evidence is forthcoming the diversions were permanent ones.

The diversion of the Middle Ohio or old Kanawha system into the Lower Ohio can not be referred so confidently to glaciation as the diversions just mentioned, nor is the available evidence such that any other factors can be cited to have caused the diversion. Further attention is given this matter under the subjects of "Piracy" and "Earth movements."

The diversions near Cincinnati are probably in large part due to glaciation. It is, however, possible that the diversion past the south side of the Walnut Hills resulted from stream piracy prior to the earliest glaciation of the region. Whether the diversion from the old channel past Hamilton to the present direct channel from Cincinnati to the mouth of the Ohio took place as late as the Illinoian stage of glaciation or at an earlier stage has not been determined.

The changes along the old Kanawha system by which Teays Valley and the valley south of Ashland, Ky., became abandoned are perhaps indirectly due to glaciation. The ponding of waters probably extended into these valleys at each glacial stage down to the Iowan. The amount of erosion accomplished after the diversions took place is, however, so great that the diversions seem likely to have occurred as early as the earliest stage of glaciation.

PIRACY.

Where one drainage system has an advantage over an adjoining one, shiftings of the divides and even important changes in drainage courses may result. It is probable that such shiftings and changes have been common in early stages of development of drainage systems. They appear also to have taken place to some extent in drainage systems that are somewhat

mature. In the discussion of features on the portion of the Ohio between Moundsville and New Martinsville attention was called to evidence that the divide had shifted toward Moundsville because of an advantage held by a drainage line that led southwestward from New Martinsville over one that led northward. It is probable also that the channel which connects Big Bone and Eagle creeks with the Ohio near Warsaw, Ky., became abandoned through piracy, though the precise mode of capture is not yet understood.

The changes in drainage just mentioned are of minor consequence compared with changes which were effected by glaciation; but there is a chance that piracy will prove to have been influential in causing changes of great consequence in this region. The diversion of the Middle Ohio or old Kanawha system into the Lower Ohio system seems so remote an event, if we may judge by the work accomplished since it took its present course, that one hesitates to refer it even to the earliest of the several stages of glaciation. But the difficulties of accomplishing this diversion by piracy are perhaps not less than in extending the glaciation far enough back to give time for the work to be done. In discussing this matter, Chamberlin writes: "It would seem to be a rather extraordinary feat of piracy that a river should be able to eat its course back across the Cincinnati arch and drain country in a synclinal beyond, when there were courses of drainage which essentially avoided the arch." The applicability of piracy to this and also to other places in the Ohio drainage system can hardly be decided in the present stage of investigation.

EARTH MOVEMENTS.

Earth movement or crust warping may prove to have had influence in causing diversions in the old systems of drainage either by itself or in combination with stream piracy. As already suggested, it may have been through these agencies that the old Kanawha was diverted from the Scioto Basin to the Lower Ohio prior to the earliest glaciation. But it is perhaps idle to speculate on this question, since the date of the flexure at the north end of the Scioto Basin is unknown and various other conditions are uncertain. Not only here, but elsewhere in the region under discussion, the influence of earth movements upon drainage embraces a broad range of problems which can scarcely be dealt with at present. The possible variations in influence are forcibly illustrated in districts adjoining the one under discussion, and with these illustrations the writer will leave this question.

Recent investigations by Gilbert, Spencer, Taylor, and others have brought to light evidence that earth movements have produced marked changes in the drainage of the Great Lakes and their expanded predecessors. Because of northward differential uplift the drainage of the three upper lakes (Superior, Michigan, and Huron) has been thrown into a course farther south than it formerly took, the old course being eastward from Georgian Bay to the Ottawa River instead of past Niagara Falls. The limits of change may not yet have been reached, for the movement appears to still be in progress, and if it continues to the amount of only a few feet the discharge of the upper lakes will be diverted from Niagara to Chicago, and they will then be connected with the Mississippi instead of the St. Lawrence system. Changes of this class and magnitude illustrate the great influence which earth movements may have upon drainage under favorable conditions. On the other hand, very great earth movements have taken place in some localities which apparently have had but little influence upon the drainage. The Susquehanna River crosses the entire Appalachian system, and yet seems to have maintained its course faithfully, notwithstanding it was antagonized by the maximum flexure of the mountain system. The Delaware, the Juniata, the Potomac, and even the upper waters of the Kanawha furnish illustrations of similar persistence.

From these illustrations it appears that the rate of movement must be sufficiently slow for a stream to cut down its passage across the rising arch if there is to be no diversion. It may also be inferred that a stream flowing at a low gradient might be diverted, as well as a lake, by such a movement as that which has produced the changes in the drainage of the Great Lakes. Indeed, the South Fork of Chicago River will be changed to a lake and finally made to reverse its present course if the change in the discharge of the Great Lakes from Niagara to Chicago is effected.

SECTION II. ST. LAWRENCE SYSTEM.

In the present discussion only that portion of the St. Lawrence system is considered that lies within the territory covered by this report. It includes the southern tributaries of Lake Ontario from the Genesee westward to the Niagara River, Tonawanda Creek, an eastern tributary of Niagara River, and the southern and western tributaries of Lake Erie in New York, Pennsylvania, and Ohio. The discussion begins with the Genesee River and proceeds westward to the western end of the Lake Erie Basin.

GENESEE DRAINAGE BASIN.

GENESEE RIVER.

Genesee River, which forms the east boundary of the region under discussion, rises in the Allegheny Mountains in northern Pennsylvania and flows northward across western New York, entering Lake Ontario a few miles north of the city of Rochester. The accompanying map (fig. 8), prepared by Fairchild, shows the leading features. The drainage basin is about 100 miles long and perhaps 40 miles wide. It is broadest in the northern half, the southern end for a distance of about 35 miles from the head of the basin being but 10 to 20 miles wide. The area of the drainage basin is estimated by Rafter to be 2,445 square miles.[1]

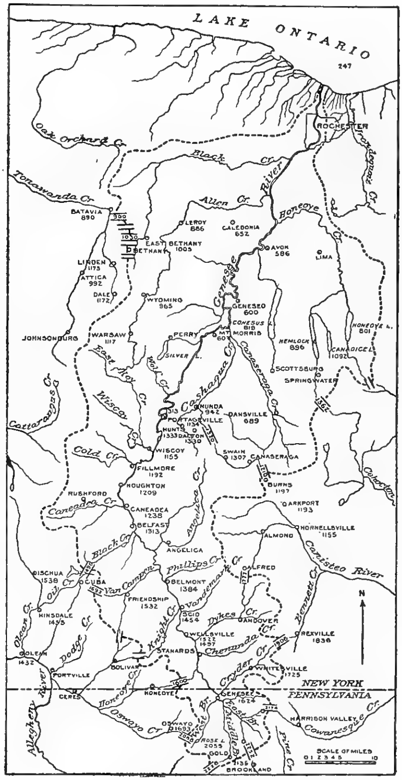


FIG. 8.—Hydrography of the Genesee Valley, by H. L. Fairchild. This map is reproduced from Fairchild's paper in the Bulletin of the Geological Society of America, Vol. VII, 1895, Pl. XIX. Water partings are shown by heavy broken lines. Glacial lake outlets are indicated by bars transverse to the water parting. Figures indicate altitude above mean tide.

The upland surface at the head of this drainage system attains an altitude of about 2,500 feet, but there are passes connecting the headwaters of the Genesee with the headwaters of the Allegheny and with branches of the Susquehanna that are 250 to 400 feet lower than the high uplands. One of these near Bingham, Pa., is 2,174 feet; another near Ulysses is 2,252 feet; and one near Gold is 2,228 feet (Fairchild). There is a still lower pass (2,068 feet) connecting the West Branch of Genesee River with the head of Oswayo Creek, a tributary

[1] Water-Supply Paper U. S. Geol. Survey No. 24, 1899, p. 26.

of the Allegheny River. There are other passes at the heads of tributaries which are markedly lower than the passes at the head of the drainage basin. The lowest connecting with the Allegheny drainage is near Cuba, New York, 1,496 feet above tide; but one near the New York and Pennsylvania State line, connecting with Honeoye Creek, a tributary of Oswayo Creek, is only 1,600 feet. The lowest pass connecting with the Susquehanna is at Burns, N. Y., 1,210 feet.

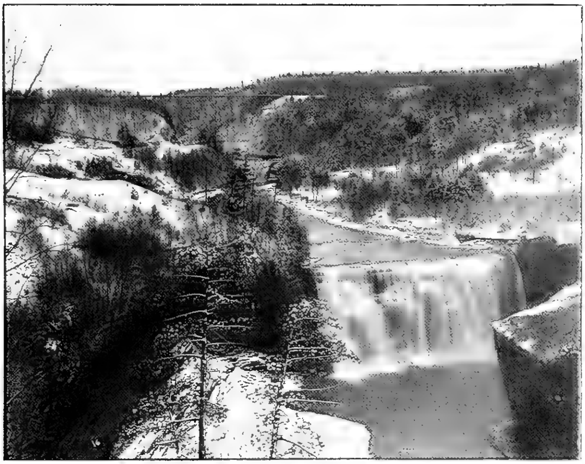
In the southern half of the basin the tributaries are all small. The longest eastern one is Angelica Creek, with a length of 25 miles, and the longest western one is East Coy Creek, with a length of 25 to 30 miles. In the northern half there are four tributaries whose length is about 50 miles—Canaseraga and Honeoye creeks from the east and Oatka or Allens and Black Creek from the west.[1]

The Genesee River follows, in the main, the line of a preglacial valley; but, as pointed out by Hall many years ago, it makes slight incursions into the west bluff of the old valley at places where the preglacial valley was greatly filled with drift. It was also thought by Hall that the mouth of the preglacial valley was at Irondequoit Bay.[2] The principal deflections of the stream are between Portage and Mount Morris and in the vicinity of Rochester. The following concise description of the deflection at Portage was presented by Hall at the meeting of the Association of American Geologists and Naturalists in 1843, and reported in the American Journal of Science for that year. A similar description appears in his report of the Fourth District, also published in 1843:

> The river to the south of Portage flows in the bottom of a broad valley extending toward the north. At Portageville the stream bends around to the left, and, after flowing a short distance nearly south, turns to the north and northeast, cutting its channel through the rocky slate in some places to the depth of 350 feet, and forming in its passage three falls of 66, 100, and 96 feet, respectively. This channel is narrow, with mural banks; but a short distance below the lower falls it emerges into a broader valley in a line with the channel to the south of Portage before it is deflected from its course. The space between these two points is a deep, broad gorge, filled to a great height with clay, sand, and gravel. This is evidently the ancient channel of the river, and yet, after it had become filled with this drift, the stream found an easier passage by excavating the solid rock for 3 miles than by removing these loose materials.
>
> Still below this point the river leaves the broad channel and excavates a gorge through the shales, emerging into the broad valley at Mount Morris.

[1] It should be noted that the Genesee River has two western tributaries called Black Creek. The name Honeoye is also applied to two streams here discussed.

[2] Geology Fourth Dist. of New York, by James Hall, 1843, pp. 344, 422.



A. MIDDLE FALLS OF GENESEE RIVER AT PORTAGE, N. Y.

B. GENESEE RIVER CANYON BELOW MIDDLE FALLS.

It has been pointed out by Fairchild that the valley followed by the Genesee between Portage Falls and the deflection at Mount Morris is the prelacial valley of some tributary of the old river.[1] The preglacial course from Portage was apparently eastward, past Nunda, into the valley now occupied by Kishawa Creek, and thence north to the present Genesee just below Mount Morris. Grabau has suggested a westward course, past Castile, to the valley of Oatka Creek near Warsaw, and thence northward down that valley to the lowlands near Leroy, beyond which its course is not given.[2] In suggesting this course he apparently overlooked the broader and more direct line past Nunda. It is also a mere conjecture that a buried valley connects the Genesee past Castile with Oatka Valley. The present divide, it is true, carries a larger deposit of drift there than at points farther north and south, but it seems likely to be the site of one of the low passes or cols that characterize this region.

At Rochester the Genesee enters another gorge, which extends to Lake Ontario, a distance of 7 miles. In this gorge there are three falls made in passing over the Niagara, the Clinton, and the Medina formations, with heights of 90, 20, and 94 feet, respectively. Concerning these falls, Hall has given the following interpretation:[3]

The different rates of recession in waterfalls is shown when the successive rocks are of different degrees of hardness, producing a series of falls. This happens when the highest are more destructible than the lower, and by this means the upper fall outruns the others. The Genesee River at Rochester presents an example of this kind, where the Medina sandstone, the rocks of the Clinton group, and the Niagara group have each produced a distinct fall. This, at one period, was doubtless a single cascade; but the upper shale wearing away faster than the rocks below, allowed the fall to travel rapidly southward till it came to the limestone surmounting the shale, where its progress was somewhat arrested. At the present time it seems probable that the lower fall is receding faster than the upper, which is thus protected.

The upper fall is now upon the northern edge of the limestone, which increases in thickness for 2 miles south, being a medium of constantly augmenting resistance, while the Medina sandstone and the limestone of the Clinton group are no thicker and no more difficult to wear away than they have been for centuries past. Thus it is plain that, under otherwise equal circumstances, the lower falls will advance upon the upper until the whole will become one. It will not then, however, be of the

[1] Bull. Geol. Soc. America, Vol. VII, pp. 427–429.

[2] The preglacial channel of Genesee River, by A. W. Grabau: Proc. Boston Soc. Nat. Hist., Vol. XXVI, 1894, pp. 359–369.

[3] New York Geol. Survey, Fourth District, 1843, pp. 381–382, fig. 184.

height of all these; for the long rapid between the upper fall and the present place of the lower one will be nearly as much descent as the fall at present.

These speculations are offered not with a view to any practical bearing, but to correct an erroneous impression which arises from the first view of these falls. Since there are now three falls, and since we suppose there was a period when only one existed, it is natural to infer that the same cause that first produced a separation would continue to operate to perpetuate the same condition. This would doubtless be true so long as the nature of the strata remained the same; but it is equally evident that any change in these will change all the other conditions.

In Pls. X and XI views of the falls and gorge near Portage, and of the middle and lower falls near Rochester, are presented.

GENESEE GLACIAL LAKES.

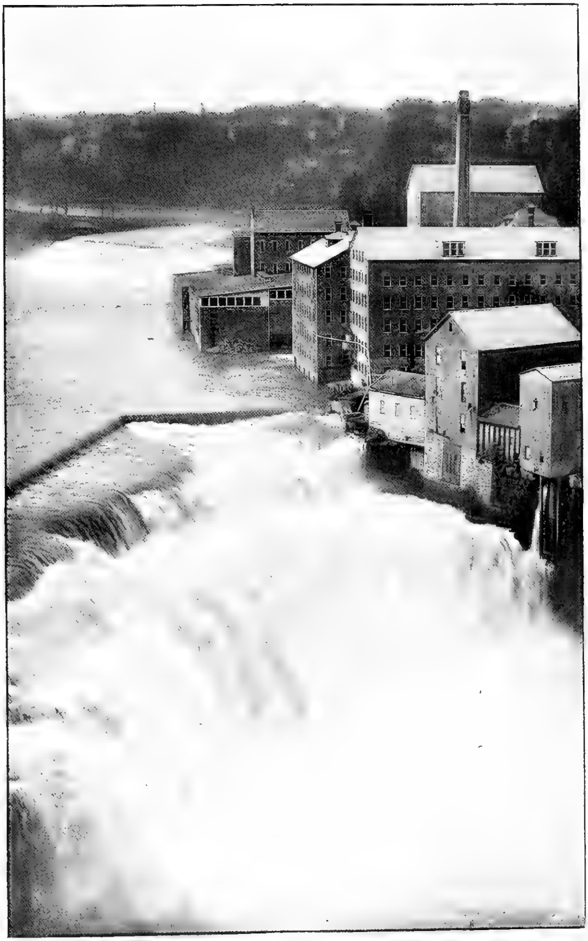
It was Hall's opinion that subsequent to the deposition of the drift the portion of the Genesee north from Mount Morris was occupied by a lake. The lake is supposed to have been held by a "barrier on the north," but the nature of the barrier is not stated.[1] Later investigations point strongly to the ice sheet as the barrier.

A special study of the evidence that lake waters occupied the Genesee Valley in the Glacial epoch has been made by Fairchild, whose results are given in the Bulletin of the Geological Society of America.[2] Attention is called to the peculiarly favorable conditions for the formation of glacial lakes during both the advance and the retreat of the ice sheet. The traces of the former have been obliterated, for at its culmination the ice sheet extended southward beyond the limits of the Genesee Basin. The paper is therefore devoted chiefly to a description of the features produced by the waters held in by the ice barrier during the northward retreat and later by barriers of drift that were formed by the ice sheet.

Beaches or other shore-line features are necessarily weak, as the expanse of water was not sufficient to give rise to strong waves and as the waters were not long stationary at any particular plane, the height varying with the season and the downcutting of the outlets. Deltas formed by land streams and also glacial stream deltas were well developed. Wave-built and wave-cut terraces also are prominent features. It was found that these deltas and terraces harmonize in level with neighboring outlets on the borders of the drainage basin, and that in passing from the southern

[1] New York Geol. Survey, Fourth District, 1843, p. 344.

[2] Glacial Genesee lakes, by H. L. Fairchild; Bull. Geol. Soc. America, Vol. VII, 1896, pp. 423–452.



MIDDLE AND LOWER FALLS OF GENESEE RIVER AT ROCHESTER, N. Y.

toward the northern end of the drainage basin one can recognize several water plains, each of which is in harmony with an outlet. The following summary of these stages is given by Fairchild:

> The first stage in the glacial drainage of the valley was from the headwaters to both the Susquehanna and the Ohio-Mississippi, with altitudes of water surfaces over 2,200 feet.
>
> The second, third, and fourth stages drained to the Ohio-Mississippi, with altitudes respectively 2,068, 1,600, and 1,496 feet.
>
> The fifth and sixth stages drained to the Susquehanna, with altitudes of 1,320 and 1,210 feet.
>
> The seventh and eighth stages drained to the Illinois-Mississippi, with altitudes from 1,200 down to 880 feet.
>
> The ninth stage drained to the Hudson, with an altitude of 435 to 440 feet.[1]
>
> The tenth stage is the nonglacial St. Lawrence drainage, with present altitude of 247 feet.

The several outlets utilized by these lakes show marked differences in the amount of cutting, suggesting great differences in the duration of the lake levels. The first outlet that shows evidence of long operation is the one at 1,600 feet, which discharged westward through Honeoye and Oswayo creeks to the Allegheny River. The amount of downcutting here, as estimated by a delta at the mouth of a gully at the east border of the col, is 60 to 70 feet, and the width of the rock gorge 1,000 feet. The excavation is in soft shales. The next lower outlet, 1,496 feet, which leads past Cuba, seems to have encountered no rock, but simply leveled the drift filling at the summit, the channel being spacious and near to grade. In the next stage the waters in the Genesee Valley apparently dropped to about 1,320 feet and discharged through a channel at the head of Canaseraga Creek into Dansville Lake, and thence by a channel past Burns to the Chemung-Susquehanna. But in course of the retreat of the ice sheet a passage was opened to Dansville Lake at a level sufficiently low to cause the Genesee Lake to drop to the level of the outlet past Burns, 1,210 feet. This outlet is reported by Fairchild to be the grandest of the abandoned water courses. Its width is about three-fourths of a mile and its length 12 miles. It has a fall of but 10 feet in the first 6 miles and of but 40 feet in the second. Flood plains are seen all the way from Burns to Hornellsville at a height of 15 to 30 feet over the channel. It is thought that the effective life may have been

[1] Since writing the above Professor Fairchild has recognized a stage of eastward discharge higher than this, which is marked by the Geneva Beach and which he calls the Lake Dana stage. The Geneva beach: Bull. Geol. Soc. America, Vol. VIII, 1897, pp. 281–284; Lake Dana: Vol. X, pp. 56–57.

shorter than that of some of the higher outlets, but it carried a much greater volume of water. The next stage marks the close of the Genesee Lake as a local body of water. It then became merged with the great body known as Lake Warren, and discharged westward to the Mississippi. At the Lake Warren and later stages definite beaches were formed, which are considered in Chapter XVI.

MORAINAL LAKES.

Passing over minor pondings of the river occurring as a result of irregularities in the drift filling, only the three most conspicuous cases of damming are considered; one of these is at Portageville, another at Mount Morris, and the third above Rochester. These have all received the attention of Fairchild,[1] whose descriptions are here given:

At Portageville the broad, deep valley was completely dammed with drift, and the river found its outlet over the east rock wall of the buried valley. After cutting through perhaps 75 feet of drift the river had to cut through about 125 feet of Portage shales before the lake was drained. This probably required a length of time comparable to the life of one of the stages of glacial waters.

The top of the rock cut is about 1,250 feet by estimate, and it seems probable that all the numerous and strong terraces found in the valley from Portage up to Caneadea and below about 1,275 feet altitude belong to the morainal lake. At Portageville there are good terraces at 1,157 and 1,185 feet, and others by aneroid at 1,220, 1,255, and 1,265 feet. At Rossburg are conspicuous plateaus, the lower ones possibly detrital river plains, but higher ones at about 1,200 feet and over. At Fillmore the terraces are 1,218, 1,233, and 1,252 feet, and at Houghton is a good terrace, estimated at about 1,250 feet. At Caneadea the terraces are well developed and have altitudes of 1,243 and 1,273 feet.

The St. Helena morainal lake, which existed in the postglacial part of the Genesee Valley above Mount Morris, has not been studied. The top of the rock gorge, locally known as the "high banks," is not far over 900 feet. The cut, about 300 feet deep, is in dark Hamilton shales and was made during the Warren and Iroquois stages. On account of the narrowness of the valley and the steepness of the slopes, the water planes of the morainal lake are not well preserved, but can undoubtedly be found by searching.

A shallow morainal lake probably existed southwest of Rochester, due to the morainic dam which the river has cut through at the "rapids." This lake could not have been over 560 feet in altitude, the height of the drumloid barrier on the east, and was probably only 540 to 550 feet, the present altitude of the moraine. It could, therefore, not have been deep, but it extended up the valley several miles, and had a broad expanse east and west, with very irregular form. For the brief episode of its existence this lake received from the river a large amount of detritus, which was deposited as a smooth floor, with an altitude of 525 feet, making the largest level tract in the region of Rochester.

[1] Bull. Geol. Soc. America, Vol. VII, pp. 449–450.

CHANGES OF DRAINAGE ON THE TRIBUTARIES.

The changes of drainage in the southern portion of the basin are of minor importance, and consist chiefly of slight incursions of the present streams into the edges of the old valleys. These deflections are due to a higher drift filling in the middle of these valleys than on the borders. In some cases the lower ends of valleys were filled to a greater height than the middle portions, thus forming morainal lakes in the middle portions. In opening a passage to the Genesee these have in some cases cut down into the old valley slope instead of into the deep part, and thus opened rock ravines near the mouth. One of the most impressive of this class is found on the lower course of Caneadea Creek below the village of Rushford, where the morainal dam rises nearly 200 feet higher than the part of the valley above it.

In this headwater portion of the Genesee drainage basin the writer has had opportunity to visit only a few of the passes that connect the Genesee with streams discharging westward, and none of those discharging eastward, and can not speak positively concerning shiftings of the divide. The pass at Cuba appears to have its present divide several miles nearer the Genesee than the old divide, there being a marked constriction in the valley of Oil Creek several miles below Cuba which may mark the old divide. The amount of drift is so great as completely to cover the old col if it stands in this constriction. A stream entering Oil Creek from the south at Cuba seems to have formerly discharged northeastward to the Genesee at Belfast. (See Pl. V.)

Fairchild has expressed the opinion that the headwater portions of several of the tributaries of the Susquehanna in western New York formerly discharged northward into the Lake Ontario Basin.[1] Possibly the headwater portion of Canesteo River discharged from Arkport northward past the low divide at Burns into the Canaseraga Valley and thence to the Genesee.

In the northern portion of the Genesee drainage basin the old lines of discharge for tributaries evidently are not followed by the present lines. The latter not infrequently are cutting trenches in the rocks, and in a few cases have waterfalls. The filling with drift has completely concealed the old drainage lines over much of the area drained by Black Creek and the lower courses of Oatka and Honeoye creeks.

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[1] Bull. Geol. Soc. America, Vol. X, 1899, p. 30.

The headwater portion of Oatka Creek is in the midst of morainic knolls and ridges which conceal the preglacial features as far north as the vicinity of Warsaw. Here is entered an old valley, one-half to three-fourths mile in width, which leads northward through elevated uplands into the lower tract lying between the Corniferous and Niagara escarpments. The stream now turns eastward near Leroy and joins the Genesee, but the preglacial channel probably continued northward. The course of the preglacial channel is certainly not coincident with that of the present stream even above the deflection near Leroy, for the latter flows on rock ledges and has an important waterfall, known as "Buttermilk Falls," just north of that village. Because of the great filling of drift north of Leroy, it will be difficult to determine the course of the preglacial line.

It is thought by Fairchild that several of the tributaries of the Genesee held small glacial lakes at higher levels than the lakes in the neighboring portions of the Genesee Valley. One in the valley of Knight Creek had an outlet from its head westward past Bolivar. The evidence of a discharge across the col at the head of this valley is clear. The altitude is so great that it can not have been the discharge for the Genesee glacial lake. There is equally clear evidence of the westward discharge of a small glacial lake in Van Campens Creek Valley along a line utilized by the Erie Railroad. There is a well-defined scourway across the present divide at an altitude of 1,692 feet, which is nearly 100 feet higher than the westward outlet of the Genesee Lake into Honeoye Creek, a few miles to the south. This valley carries terraces at different levels, which are thought by Fairchild to harmonize in some cases with the local glacial lake outlet and in others with the outlets for the Genesee waters at 1,600 and 1,496 feet The morainal lake in Caneadea Creek Valley was probably preceded by a glacial lake, though the outlet of the latter was not determined. A glacial lake in Oatka Creek Valley is found by Fairchild to have first discharged southeastward, past the sites of Silver Springs and Castile, to the Genesee Lake, the altitude of the head of the channel being about 1,400 feet. With the retreat of the ice barrier this lake eventually found a line of northwestward discharge at an altitude about 100 feet lower, through a valley in which the villages of Dale and Linden stand, and thence across a pass to Tonawanda Valley. With the change of outlet the discharge of the lake passed from the Susquehanna drainage to the Mississippi. These lakes are called by Fairchild

the First Warsaw and the Second Warsaw glacial lakes. At the seventh stage of the glacial Genesee waters the ice barrier became removed sufficiently to lower this lake to the level of the Genesee waters and thus bring its distinct history to a close.[1]

Fairchild has also found evidence of the existence of small glacial lakes in the headwaters of eastern tributaries of the Genesee that discharged to the Susquehanna at higher levels than the outlet past Burns. These and the glacial lakes held in the valleys of the Finger Lakes to the east of the Genesee have furnished him the material for a very interesting chapter of glacial history, but they lie outside the district covered by the present report. The four papers already published by Fairchild in the Bulletin of the Geological Society of America[2] describe in detail much that can be only briefly summarized here.

MINOR TRIBUTARIES OF LAKE ONTARIO IN WESTERN NEW YORK.

Oak Orchard Creek is the most important southern tributary of Lake Ontario between the Genesee and Niagara rivers. Its headwater portion lies on the plain between the Niagara and Corniferous limestone escarpments immediately west of the headwaters of Black Creek and drains portions of Genesee and Orleans counties. In southwestern Orleans County it turns northward through the Niagara escarpment, near Medina, where it has a series of falls, and then takes a northeastward course into Lake Ontario. The falls, three in number, a section of which appears in Hall's report on the Fourth district, occur in the passage over the Medina sandstone and Clinton limestone, as well as at the Lockport (Niagara) limestone. It is doubtful if the stream in any part of its course follows a preglacial drainage line, for the portions in which it is free from rapids and cascades are in plains heavily covered with drift. The headwater portion is exceedingly sluggish and is bordered by swamps, which have required a large amount of artificial drainage.

The remaining tributaries of Lake Ontario in western New York head in the Niagara escarpment and flow usually more or less directly across the plain between that escarpment and the lake. Johnsons Creek, however,

[1] Bull. Geol. Soc. America, Vol. X, 1899, pp. 33–34.

[2] Glacial lakes of western New York, Vol. VI, 1895, pp. 353–374. Glacial Genesee lakes, Vol. VII, 1896, pp. 423–452. Lake Warren shore lines in western New York and the Geneva beach, Vol. VIII, 1897, pp. 269–286. Glacial waters in the Finger lakes region of New York, Vol. X, 1899, pp. 27–68.

takes a northeastward course from eastern Niagara County across northwestern Orleans County, thus greatly increasing the distance to the lake. Eighteenmile Creek flows for several miles in a southwestward course before turning northward into the lake, its course being governed to some extent by the Iroquois beach.

TONAWANDA CREEK.

Tonawanda Creek consists of two quite distinct portions: First, a north-flowing portion, leading from Wethersfield Township, Wyoming County, northward in a deep valley through elevated uplands to Batavia, near which it enters the lowlands that lie south of Lake Ontario; second, a west-flowing portion, leading from Batavia to the Niagara River at Tonawanda. Between Batavia and Indian Falls the stream flows on the plain back of the Corniferous escarpment. It descends in a cascade at Indian Falls to the plain lying between the Corniferous and Niagara escarpments, and flows in that plain to its mouth. This lower portion of Tonawanda Creek, the headwater portion of Oak Orchard Creek, and the entire basin of Black Creek are thus controlled by the geologic structure. They follow the lowest parts of the plains between the two escarpments and traverse a region coated to considerable depth with drift. Whether the lower course of the Tonawanda follows that of a preglacial line is not fully determined, though it seems probable that a preglacial line had approximately the same position as the present stream. The course from near Batavia to Indian Falls is independent of preglacial lines and is determined apparently by the accidents of drift filling. The north-flowing portion above Batavia appears to correspond closely with that of a preglacial line, but the latter, instead of turning westward near Batavia, is thought to have continued in a course east of north into the Lake Ontario Basin, traversing a district now drained in large part by Black Creek.

The headwater portion of Tonawanda Creek was occupied by a glacial lake, which, as found by Fairchild, discharged at first westward to Buffalo Creek, a tributary of Lake Erie, from a point about 2 miles south of Johnsonburg, and at an estimated altitude of 1,410 feet.[1] A study of stream deltas leads Fairchild to think that there are two water levels lower than the one that discharged through the outlet, one being at about 1,300

[1] Bull. Geol. Soc. America, Vol. X, 1899, p. 33.

feet and the other still lower. He has not traced out the lines of discharge for these lower water levels, but supposes them to be on the western border of the valley. As indicated above, the lake in this valley received for a time the outflow from the Second Warsaw Lake in the Oatka Valley.

TRIBUTARIES OF LAKE ERIE.

The present southern and western tributaries of Lake Erie drain about 12,000 square miles in northern Ohio, about 1,000 square miles in northeastern Indiana, about 600 square miles in northwestern Pennsylvania, and about 1,500 square miles in southwestern New York. This embraces but a small part of the area that was tributary to the Lake Erie Basin in preglacial times. As indicated above (pp. 127–148), the present Allegheny system of drainage is made up of independent preglacial lines which entered the Lake Erie Basin by three or more distinct lines of discharge. Indeed, the entire drainage of the present Ohio in western Pennsylvania and eastern Ohio, with adjacent parts of West Virginia, appears to have discharged into the Lake Erie Basin. Possibly the old Kanawha, with much of the Muskingum drainage basin, was formerly tributary to the Lake Erie Basin, though, as already indicated, the evidence is somewhat in question.

In the present discussion the several southern tributaries of Lake Erie are taken up in order, beginning at the east and passing westward to the western end of the lake.

BUFFALO CREEK.

Buffalo Creek, which enters Lake Erie in the southern part of the city of Buffalo, constitutes a line of discharge for several small streams which head in the elevated uplands of southeastern Erie and western Wyoming counties, N. Y. These small streams lead northward through preglacial valleys into the lowlands that lie south of the Corniferous escarpment, but on the lowlands their courses appear to be largely independent of preglacial lines. Borings in the vicinity of Buffalo have brought to light a preglacial channel occupied for a few miles by Buffalo Creek, whose rock bottom is about 80 feet below the surface of Lake Erie.[1] What proportion of the present drainage basin of Buffalo Creek discharged through this preglacial line has not been determined. It is probable, however, that the eastern

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[1] See Pohlman: Proc. Am. Assoc. Adv. Sci., Vol. XXXII, 1883; also Trans. Am. Inst. Min. Eng., Vol. XVII, 1889.

portion of the drainage basin had a northward discharge to a valley draining the lower course of Tonawanda Creek The deflections of tributaries of Buffalo Creek in passing the Crittenden or Forest beach are notable, as shown in the discussion of that beach on a subsequent page.

EIGHTEENMILE CREEK.

This tributary of Lake Erie enters the lake about 18 miles southwest of Buffalo, and this fact is probably responsible for the name applied to the creek. It is formed by the union of two streams which have their headwaters in the elevated uplands of southern Erie County and which flow northwestward through deep preglacial valleys into the plain bordering the lake. Their junction is only about 5 miles from the mouth of the stream. It is probable that the preglacial continuation of the East Fork was northward from near Hamburg into Lake Erie, though the precise line of continuation is not known. The West Fork probably entered the Lake Erie Basin along a different line from the present course of the creek, for the stream is now excavating a rock gorge near its mouth but little wider than the stream bed. It is possible that the East and West forks had a common line of discharge farther north than the present mouth of the creek. There is, however, a belt of thick drift immediately south of the mouth of the present stream, as shown by wells in the vicinity of Derby, and this may prove to have been the line of discharge for the West Branch.

CATTARAUGUS CREEK.

Cattaraugus Creek enters Lake Erie at the village of Irving, about 12 miles east of Dunkirk, N. Y. It drains a large area in Cattaraugus County, N. Y., but has only small tributaries from Erie and Chautauqua counties, while its headwaters drain a small portion of Wyoming County and the extreme northwest corner of Allegany County. Its source, like that of Tonawanda Creek, is in Wethersfield Township, Wyoming County, in the midst of a great interlobate morainic belt. It has a general westerly course from source to mouth. The northern tributaries are very small, but the southern tributaries reach, in several cases, a length of 12 to 15 miles, while the length of South Fork is fully 25 miles. The present limits of the drainage basin are largely determined by drift obstructions.

In a paper prepared in 1894 by Chamberlin and the writer, evidence was set forth that the lower course of Cattaraugus Creek constituted the

line of discharge for the preglacial Upper Allegheny.[1] The greater part of the present basin of Cattaraugus Creek appears to have been tributary to the old Upper Allegheny from the east and to have joined that valley near the mouth of Clear Creek, opposite Versailles. The old basin of Cattaraugus Creek included the headwater portions of Ischua Creek and probably of Great Valley Creek, now tributary to the Allegheny. The old divide on Ischua Creek appears to have been just south of the village of Ischua, fully 15 miles from the present divide near Machias. The present drainage departs considerably from the preglacial line near the junction of the South Fork with the main stream. The South Fork appears to have formerly taken a course east of north from the village of Cattaraugus, past Waverly, to join the east or main fork about 5 miles above the present point of junction. The united stream then took a northwestward course, passing just south of Collins Center and Lawton to the lower course of Clear Creek. Between the old junction and the present one Cattaraugus Creek is flowing through a rock gorge no wider in places than the bed of the stream. South Fork also enters a similar gorge about 5 miles northwest of Cattaraugus, which continues to the junction with the main creek. A short distance below the present junction with the main creek the old valley of the Upper Allegheny is entered. The present creek does not traverse the deepest portion of that old valley, but follows its west bluff, and for a few miles in the vicinity of Versailles it is cutting a rock gorge in the face of that bluff.

The drainage basin of Cattaraugus Creek is limited on the north and east by morainic belts. It is scarcely probable that these follow a preglacial divide, though the position of the preglacial divide has not been fully determined. Possibly the headwater portion of Cattaraugus Creek discharged northwestward through valleys now tributary to Buffalo Creek.

The old drainage basin of which Cattaraugus Creek formed a part is discussed in connection with the Upper Allegheny River (pp. 129–132).

SMALL TRIBUTARIES BETWEEN CATTARAUGUS AND CONNEAUT CREEKS.

The tributaries of Lake Erie between Cattaraugus and Conneaut creeks find their sources in the prominent escarpment which borders the lake in southwestern New York and northwestern Pennsylvania. Their sources are seldom more than 15 miles distant from the lake, and the longest streams are

[1] Am. Jour. Sci., 3d series, Vol. XLVII, 1894.

scarcely 25 miles in length. The lower courses of these streams appear to be largely independent of preglacial lines. The headwater portions often occupy depressions in the escarpment nearly in line with streams which lead southward from the escarpment. The present divide in these low places on the escarpment is in several cases a morainic ridge, and this apparently lies north of the preglacial divide.

CONNEAUT CREEK.

Conneaut Creek has its source in a moraine near Conneaut Lake in western Crawford County, Pa. The headwaters lead down into a broad valley which is continuous with the valley that contains Conneaut Lake and Conneaut outlet, which are tributary to the Allegheny River through French Creek. The course of Conneaut Creek is northward for about 20 miles to a point not more than 10 miles from the border of Lake Erie. It there turns abruptly westward and flows between morainic ridges for a distance of perhaps 15 miles to the village of Kingsville, Ohio, where it breaks through the north morainic ridge and takes a northeastward course to Lake Erie.

The valley occupied by the north-flowing portion of Conneaut Creek evidently drained a basin which was very different from that of the present creek and which discharged directly northward into the Lake Erie Basin across the northwestern part of Erie County, Pa. The probable extent of the old basin is discussed in connection with the Middle Allegheny. It was thought by Carll that Conneaut Creek constituted the former line of discharge for much of the present drainage basin of French Creek and the headwater portion of Oil Creek. It is found, however, that French Creek crosses two cols in passing southward from Cambridge to Meadville, which necessitates an interpretation different from that given by Carll. Instead of turning southward from Cambridge the old line of discharge for the headwater portion of Oil Creek and much of French Creek apparently was northwestward across Erie County to the Lake Erie Basin, as indicated in the discussion of French Creek drainage (pp. 138–143).

The west-flowing portion of Conneaut Creek, being determined by morainic ridges, shows little, if any, dependence upon preglacial lines. It is mainly in a rock gorge, though in places the drift extends below the level of the stream bed After passing through the moraine near Kings-

ville, the stream is given an easterly course for a few miles by a beach line which lies on its north side. Upon breaking through this line it passes directly toward the lake.

ASHTABULA CREEK.

Ashtabula Creek is a small stream which enters Lake Erie near the city of Ashtabula, in northeastern Ohio. Its source is in a morainic belt or elevated uplands near Andover, Ohio, from which it flows northward through a preglacial valley or drift-filled depression to lowlands bordering Lake Erie. It there is deflected westward a few miles by a morainic ridge, but breaks through this ridge near Ashtabula and takes a direct course into Lake Erie. Its lower course is through a narrow valley cut in shale to a depth of 75 to 100 feet, and is evidently independent of preglacial drainage lines. The drift-filled depression which it follows in its upper course was probably occupied by a preglacial stream that headed farther south than the present divide, but the precise position of the old divide has not been determined.

GRAND RIVER.

Grand River is a small stream draining the basin from which it receives its name (see p. 74). Its northerly course is through the former outlet of the old Monongahela drainage system, and, like Conneaut and Ashtabula creeks, it is diverted westward near the border of Lake Erie by a morainic ridge running parallel with the lake shore. This morainic ridge holds the stream in a westerly course nearly to its mouth at Painesville The preglacial stream which discharged through the Grand River Basin came to the present shore of Lake Erie a few miles west of Ashtabula, near the village of Geneva. Grand River, like Conneaut Creek, encounters rock strata throughout much of its westward course, and there flows in a narrow gorge, strikingly in contrast with the broad, shallow valley of the Grand River Basin.

CHAGRIN RIVER.

Chagrin River has two headwater forks, each of which finds its source in marshes among the knolls of an interlobate moraine, on the elevated upland east of the Grand River Basin. The two streams unite near Chagrin Falls, above which point the valleys are inconspicuous. At the falls there is a descent of a few feet over sandstone ledges. The stream then soon

enters a preglacial channel which has been filled to a depth of about 200 feet with drift. This old valley can scarcely have drained a large area, since the larger systems discharging through the Grand River Basin and the Cuyahoga would have absorbed nearly all the drainage except a narrow strip lying between their trunk streams.

CUYAHOGA RIVER.

The present Cuyahoga River has its head near the source of the East Fork of Chagrin River, on the uplands east of the Grand River Basin, only a few miles from the shore of Lake Erie. It leads southwestward for nearly 50 miles, away from the lake, occupying a shallow valley bordered by marshes throughout much of its course, and having an average fall of but 4.5 feet per mile. At the village of Cuyahoga Falls it makes a fall of 220 feet within a distance of 3 miles and enters a preglacial valley, which it follows northward to Lake Erie at Cleveland.

In this preglacial valley there is a heavy drift filling, both beneath the stream and on the borders of the valley Wells in Cleveland indicate that the valley floor is about 400 feet below the mouth of the present stream, or less than 200 feet above tide. Silt deposits on the borders of the valley indicate that it was filled to a height of fully 200 feet above the present stream, or to within 100 feet of the level of the bordering uplands. From these data it appears that the preglacial valley was about 700 feet in depth. Its width is scarcely 2 miles at the level of the present stream, and is probably much narrower at the level of the rock floor. Being bordered at the brow of the bluffs by ledges of resistant sandstone, it has preserved a somewhat narrow channel.

The preglacial valley occupied by the Cuyahoga in its lower course may have constituted the line of discharge for much of the region now tributary to Tuscarawas River, as indicated in the discussion of that drainage system (pp. 165–168).

ROCKY RIVER.

Rocky River has two forks, which unite near the town of Berea, Ohio. These tributaries are mainly in drift-filled preglacial valleys, but the united stream northward from Berea is largely in a new course. It crosses the preglacial valley from west to east a short distance north of this city, as pointed out by Dr. D. T. Gould,[1] who has traced a preglacial valley

[1] The Berea Advertiser, April 16, 1886.

from a point a short distance above Berea northward on the east side of that city to Lake Erie, which it enters a short distance west of the present mouth of the stream. Each of the forks has falls and rapids in passing over the Berea grit, those on the east fork being at the city of Berea and those on the west fork at the village of Olmsted Falls. The present channels of the streams are shallow above these falls and rapids, being but 25 to 40 feet in depth, but upon passing the outcrop of Berea grit the soft Cuyahoga shale is entered and a narrow canyon-like gorge 100 feet or more in average depth is excavated.

BLACK RIVER.

Two streams with this name unite at the city of Elyria and pass thence northward to the lake at Loraine. The eastern or main fork has its source on the borders of an extensive marsh near Lodi, in which a boring 210 feet in depth failed to reach rock, and flows thence northward mainly through a drift-filled valley, though not strictly coincident with it. This old valley apparently drained the headwaters of Killbuck Creek, as indicated in the discussion of that stream. At the city of Elyria occur falls nearly 40 feet in height, and the power which they furnish has recently been utilized. The west fork heads in a moraine near the village of Nova and takes a course east of north, channeling a passage much of the way through rock, its course not being so nearly in harmony with the preglacial drainage line as that of the east fork. The united stream is mainly in a new course from Elyria to its mouth.

VERMILION RIVER.

This stream heads in the midst of morainic ridges near Greenwich, and flows east of north, mainly through a rock-bound postglacial valley. It drains a somewhat elevated sandstone district. The valley is narrow throughout its course, being usually but 15 to 20 rods wide. It is scarcely 50 feet in average depth, except for a few miles near the mouth, where it is 100 to 150 feet deep.

HURON RIVER.

Huron River has its source in extensive marshes between moraines near New Haven. It drains a low district underlain by shale along the western border of the outcrop of Berea grit. Its valley is shallower than that of the Vermilion, seldom reaching 50 feet in depth.

SANDUSKY RIVER.

Sandusky River is a larger and more widely branching stream than any of the tributaries of Lake Erie thus far discussed. It consists of a westerly and a northerly flowing portion. The westerly flowing portion leads from the escarpment of Eocarboniferous sandstone near Crestline westward down the slope to the axis of the Scioto Basin. Instead of turning southward, as the neighboring streams do, to enter the Scioto River, it turns northward and flows down a gradual slope to Lake Erie. It enters Sandusky Bay at the western end. The valley of this river is small, being only 20 to 50 feet in depth and one-fourth mile or less in average width. It is in places cut into rock a few feet, and appears to be largely independent of preglacial drainage lines.

MAUMEE RIVER.

The Maumee River system has the greater portion of its drainage area within the State of Ohio, but small portions are found in Indiana and Michigan. The drainage of the two headwater forks of this system was formerly southwestward from Fort Wayne to the Wabash. At that time Lake Maumee occupied the district through which the Maumee flows, the mouth of the old lake being near the point where the St. Marys and St. Joseph rivers had their discharge. As this mouth stood higher than the portion of the basin toward the east and the portion of the outlet toward the west, there was a natural summit formed upon the withdrawal of the lake, from which the waters of the St. Joseph and St. Marys rivers were free to flow either to the east or to the west. By some accident of deposition or of slope the stream found it easier to turn eastward than to maintain its original course westward, and thus the Lake Erie drainage basin embraces these streams as well as those which have been formed in the old lake bottom or were tributary to the old lake.

The Maumee River has a length of about 150 miles and a fall of 164 feet, the source being 735 feet and the mouth 573 feet above tide. It has a shallow channel, perhaps 50 feet in average depth, excavated mainly in the drift. It is not itself a navigable stream, but is followed closely by the Wabash and Erie Canal, which for many years afforded a means of water transportation.

The St. Marys River has its source in Shelby County, Ohio, at an

elevation of about 975 feet above tide, or 238 feet above the level of its mouth. The length of the stream being about 100 miles, the average fall is scarcely 2½ feet per mile. The portion within the State of Indiana has a fall of but 18 feet in a distance of 35 or 40 miles, or about 6 inches per mile, and is, therefore, very sluggish. The course of the river, in both Ohio and Indiana, is largely determined by a moraine which lies on its north border. The descent of the river corresponds closely to that of the plain in which it flows, and the stream has formed but a shallow channel, seldom more than 25 feet in depth.

The St. Joseph-of-the-Maumee has its source in southern Michigan and flows southwestward across the northwestern corner of Ohio, entering Indiana about 35 miles above its mouth. Its length, like that of the St. Marys River, is about 100 miles. It has a more rapid fall, since its source is in a more elevated district, standing about 1,050 feet above tide. The portion in Indiana has a fall of nearly 2 feet per mile. Throughout much of its course the river flows in a narrow plain lying between two morainic ridges, and its descent is determined by that of the plain. Its valley cuts only 25 to 50 feet into the plain and has a very narrow bottom.

The principal southern tributary of the Maumee River in Ohio is Auglaize River, which enters it at Defiance. The relation of the course of this stream and of its principal tributaries to the morainic ridges may be seen by reference to Pl. XI. It will be observed that the main stream and also two of its eastern tributaries, Hog Creek and Blanchard River, have their westerly courses along the outer border of morainic ridges, while their northerly courses and the courses of the smaller tributaries are directly away from the St. Marys moraine.

It should be noted also that Tiffin River, a northern tributary entering the Maumee at Defiance, follows the outer border of the Blanchard or Defiance moraine, while its tributaries, like those of the Auglaize, lead away from the St. Marys moraine.

The drainage of the district lying between the Defiance moraine and Lake Erie, in northwestern Ohio, is in lines flowing directly away from the moraine. A large part of the drainage is into the Maumee, but Portage Creek carries the drainage of a narrow belt directly to Lake Erie.

CHAPTER IV.

THE DRIFT BORDER OR GLACIAL BOUNDARY.

It would be misleading to treat the drift border as a unit, for it is really a combination of the margins of several drift sheets which differ widely in age. A portion of the border in northwestern Pennsylvania seems to mark the limits of a drift sheet as old as the Kansan and possibly of pre-Kansan age. Immediately adjacent to this portion of the border the Wisconsin drift extends to the limits of glaciation. But upon passing to central Ohio the Illinoian drift is the one to mark the glacial limits. The Iowan is not exposed to view outside the Wisconsin within the region under discussion, though a silt apparently of Iowan age extends beyond the limits of the Wisconsin and the Illinoian in the western part of this region.

SECTION I. THE BORDER OF THE OLDEST DRIFT (KANSAN OR PRE-KANSAN).

So far as this region is concerned, the oldest sheet of drift found as an outlying deposit is restricted mainly to the northwestern part of Pennsylvania, though there may be limited exposures of it in southwestern New York and in eastern Ohio. In the central and eastern parts of the region it seems to fall short of the limits of the later drift sheets.

So far as exposed, this old drift has a very meager development on the uplands, though it is heavy in the valleys. The general thickness on the uplands probably averages less than 5 feet, while in the valleys it reaches depths of 200 to 300 feet. Because of the meager deposition on the uplands it becomes difficult to determine the precise limits of glaciation. Search is often necessary to discover even a bowlder or a pebble of glacial origin in a trip across the uplands, while valleys on either side may contain heavy deposits of drift. Until, therefore, very detailed study has been made the limits of the drift can be stated only approximately. As yet it is not known whether the border passes somewhat directly across the uplands and

valleys or is disposed in loops with protrusions down or into the valleys and with reentrants on the uplands. It is to be expected, however, that such disposition in loops would result from the topographic conditions.

An occasional bowlder has been found so far beyond the well-defined glacial deposits as to arouse suspicion of transportation through human agencies, though the object of such an expenditure of labor is not always clear. For example, a single bowlder is reported by W. S. Gresley to lie in a ravine on the south side of the Ohio River near Pittsburg in such situation that it can not be referred to stream transportation down the Allegheny and Ohio valleys.[1] The writer observed a small bowlder on an upland south of the Ohio, near the Pennsylvania and West Virginia line, that was evidently beyond the reach of the Ohio. Other bowlders that seem referable to stream action have been found on high terraces along the Ohio near Pittsburg and near Beaver, Pa. In the present state of knowledge the writer is not prepared to decide whether or not glaciation reached the Ohio at Pittsburg and Beaver. These scattering bowlders seem to be only strays that have been carried beyond the limits of glaciation, but there is a chance that they are a part of a very attenuated glacial deposit. The limit of this old drift, as given on the glacial map (Pl. II), represents merely the approximate margin of a well-defined, easily traced deposit.

The border of this old drift sheet appears to emerge from beneath the Wisconsin drift near the New York and Pennsylvania line on high uplands east of the Conewango River. It passes southward across the Allegheny River nearly to the bend of the Tionesta River at Barnesville, Pa., while the Wisconsin border passes westward across northern Warren County at a distance of several miles north of the Allegheny River. There was apparently a small lobe of the earlier ice field extending from the Allegheny Valley southward toward the bend of the Tionesta, for westward the limits of glaciation appear to be along or near the Allegheny Valley from near Warren down to Tidioute. From Tidioute to the vicinity of Oil City the border appears to lie a short distance north of the Allegheny, though probably nowhere over 5 miles from the river. In that part of its course it is 15 to 20 miles outside the limits of the Wisconsin drift. Near Oil City the border crosses to the south side of the Allegheny River, but may

[1] Am. Geologist, Vol. XVIII, 1896, pp. 331–332.

return to the north side just below Franklin. A few miles farther down, in the vicinity of Brandon and Kennerdell, it is again on the south side, but apparently crosses to the north side in the vicinity of Kennerdell, and passes southwestward through the southwestern part of Venango County. Near the common corners of Venango, Butler, and Mercer counties this drift border seems to approach closely the limits of the Wisconsin drift. From this point southwestward into Ohio there are but few places where it appears to extend beyond the Wisconsin. Bowlders and thin deposits of drift occur on uplands for a short distance outside the limits of the heavy deposits of the Wisconsin drift in Beaver County, but the writer's examinations in that region have not been sufficiently thorough to warrant an opinion as to their relation to the Wisconsin drift.

Since this drift and the evidences of its great age are discussed in a subsequent chapter, we may pass now to the portion of the border occupied by the Illinoian drift sheet.

SECTION II. THE BORDER OF THE ILLINOIAN DRIFT.

The border of the Illinoian drift seldom reaches the degree of attenuation that characterizes much of the Kansan drift border. Indeed, one usually passes within a space of less than a mile, and often in a space of a few yards, from a district that seems to be driftless to one in which the drift is a well-defined deposit several feet in depth. Yet there is seldom a marginal drift ridge or moraine. The Illinoian deposits are much heavier in valleys than on uplands, and there is a marked sinuosity of margin to conform to the topographic conditions. But notwithstanding these irregularities the border is easily mapped with a fair degree of precision; at least this is true wherever the writer has followed it.

The reentrant angle in south-central Indiana forms a natural line of separation between the Illinois glacial lobe and the part of the ice sheet to the east. For this reason, and also because the border of the Illinoian drift of the Illinois lobe has already been discussed (see Monograph XXXVIII), the discussion of its border is taken up at this reentrant angle.

The northernmost point of the reentrant angle in the Illinoian drift border in southern Indiana is on the north side of Beanblossom Creek, in northern Monroe County, a few miles north of Bloomington. From this point the border takes a course slightly south of east, entering Brown

County near Needmore, at which village, as noted by Wright in Bulletin 58 of this Survey, it crosses to the south side of Beanblossom Creek and soon rises to an elevated divide between Beanblossom and Salt creeks. The border lies along the south slope of this dividing ridge for several miles, furnishing bowlders which have been rolled down the ravines to the valley of Salt Creek. A short distance east of Nashville, the county seat of Brown County, the border crosses Salt Creek, and, swinging southward, passes through the elevated eastern range of townships occupied by the Knobstone escarpment to the extreme southeast corner of the county.

Upon passing from Brown into Jackson County, Ind., the drift border descends from the Knobstone escarpment to the low country on the east, and follows nearly the base of the escarpment southward through Jackson, northeastern Washington, and southwestern Scott counties into Clark County. It continues southward in Clark County to the Ohio River at Jeffersonville, Ind., and there makes an abrupt turn to the east, as indicated in Pl. II.

The border apparently follows up the Ohio Valley about to Bethlehem, Ind., 25 miles above Jeffersonville, before rising to the uplands south of the river, thus making a pronounced loop in the Devonian shale basin. Thence it passes in a northeast course near Bedford, the county seat of Trimble County, Ky., to the mouth of the Kentucky River, at Carrollton, Ky. East of the Kentucky River it follows nearly the divide between Eagle Creek and the Ohio River as far as the bend of Eagle Creek near Glencoe, though the ice sheet in places extended a little beyond the divide and deposited a small amount of drift in the headwaters of tributaries of Eagle Creek. From Glencoe the border leads northeastward past Richwood to the Licking River. It extends beyond the divide which separates Gunpowder Creek from Mud Lick and Big Bone creeks far enough to include the headwaters of the two last-named creeks. From near Richwood to the Licking River, Bank Lick Creek flows near the glacial boundary. On the ridge between the Licking and Ohio rivers there is but little drift, yet a few pebbles occur as far south as Fort Thomas. From Fort Thomas the drift border follows up the Ohio Valley to the vicinity of Ripley, Ohio, as long since noted by Wright.

Upon passing into Ohio, the border, as traced by Wright, crosses southeastern Brown, northwestern Adams, southeastern Highland, and northwestern Pike counties in a southwest-northeast course, and comes to

Paint Creek Valley near Bainbridge, in southwestern Ross County. It then follows this valley down to the Scioto near Chillicothe.

Having found that Wright's tracing of the glacial boundary east from the Scioto marks the limits of the Wisconsin drift, and not the limits of glaciation, the writer has made a somewhat detailed tracing of the earlier, or Illinoian, drift border in that region. From the northern part of Chillicothe the Wisconsin drift border passes northeastward to Adelphi, as indicated by Wright, but the Illinoian border lies several miles farther south. Drift is well displayed directly east from Chillicothe as far as Mooresville, a distance of 6 miles. The border there swings northeastward and follows Walnut Creek Valley to Charleston, beyond which place it continues over high hills to the valley of Salt Creek at Haynes, passing about 3 miles south of Adelphi. The occurrence of till on the elevated land south of Adelphi was noted by Wright,[1] but was not recognized as a sheet distinct from the Wisconsin drift.

From Haynes the Illinoian border leads northward to South Perry, where it apparently passes beneath the Wisconsin border. From South Perry northeastward to Clear Creek, a western tributary of the Hocking River entering about 8 miles below Lancaster, the Wisconsin drift seems to form the border, though it should be noted that in places in this part of its course its limits are a short distance beyond Wright's boundary line. On the lower course of Clear Creek a glacial terrace which seems to be of Illinoian age appears outside the limits of the Wisconsin. This terrace stands 50 feet or more above the level of the terraces of Wisconsin age found in that valley and the Hocking Valley, or about 100 feet above the creek. It carries pebbles of granite and greenstone as well as local rocks, and they are much more weathered than is the gravel of Wisconsin age.

Near Revenge, on the north side of Clear Creek, the Illinoian drift emerges from beneath the Wisconsin and passes eastward across the Hocking Valley into northern Hocking County, its border being along the valley of Rush Creek to the bend of the creek 4 miles south of Bremen. The border there takes a northeast course past Junction City. From Junction City the course is north-northeast to Jonathan Creek, passing about 4 miles east of Somerset, and coming to Jonathan Creek near the line of Perry and Muskingum counties.

[1] Glacial Boundary in Ohio, p. 61.

From Jonathan Creek the course is northward across a projecting part of Muskingum County to the "National road," about 2 miles west of Mount Sterling. It then changes to a course west of north and comes to the Licking Valley at Hanover, 8 miles east of the city of Newark. The great filling produced in the Licking Valley at the drift border is discussed below.

From the Licking Valley the border bears east of north past Fallsburg and comes to Wahatomaka Creek at Frampton, in the extreme southeast corner of Knox County. It continues with the same course to the Walhonding River, passing about 2 miles east of New Guilford, in Coshocton County, and coming to the river about 2 miles east of Walhonding. From this river the course is slightly west of north, following nearly the divide between the tributaries of Killbuck and Mohican creeks to the Wisconsin drift border a short distance west of Nashville, Holmes County. The Wisconsin drift apparently conceals its further course in northeastern Ohio.

It will be observed that the drift border just outlined forms a great loop with a length of about 400 miles, embracing an area whose width is nearly 250 miles. The border at its southernmost point, near Louisville, Ky., reaches latitude 38° 20′, which is nearly one degree farther north than the extreme limit reached by the Illinoian drift of the Illinois glacial lobe, the limits of that lobe being about 37° 35′. The reentrant in northern Monroe County, Ind., extends up to 39° 20′, giving the lobe on the east a protrusion of about 70 miles at its extreme point. The terminal portion of the loop has an indentation near Cincinnati of 15 or 20 miles, producing an incipient double lobation. The drift border on the east side of this area has a remarkable retreat to the north, the point where the Illinoian border disappears beneath the Wisconsin in western Holmes County, Ohio, being about latitude 40° 40′, or more than two degrees north of the southern extremity of the lobe.

To one examining into the causes of this irregularity of outline in the drift border, several topographic features at once present themselves. The reentrant angle in south-central Indiana lies between the great lobes, one of which moved southward through the Lake Michigan Basin, and the other through the Huron-Erie Basin. This, it is thought, will in large part account for its remaining unglaciated. The Lake Michigan Basin and the country to the southwest being an exceptionally low area, the ice sheet extended farther south than in the somewhat elevated area between Lakes

Huron and Michigan. In the district south of Lake Huron it extended much farther south than in the more elevated and broken district on its borders.

The notch in the drift border near Cincinnati appears to be about in the lee of the elevated tract in Logan County, Ohio, standing between the Scioto and Miami basins, and this relation suggests the cause for the notch or slight indentation displayed.

The reentrant in southern Indiana was no doubt made more prominent by reason of the elevated and broken country which the ice sheet there encountered, while the southward protrusion on its east border was aided by the low, smooth country in the path of that part of the ice sheet. It seems probable that these local conditions may have been responsible for a difference of several miles in the irregularity of the drift border, but they can hardly be held responsible for the lobation or protrusion of 70 miles which the border displays. The great basins encountered by the ice sheet before reaching its extreme limits appear to have been the chief factors in causing the lobation.

How far within the limits of the Wisconsin drift the border of the Illinoian drift lies in northeastern Ohio, and districts farther east, has not been determined. It will perhaps be made known by well sections.

SECTION III. THE BORDER OF THE WISCONSIN DRIFT.

The Wisconsin drift extends nearly or quite to the glacial boundary in the reentrant angle in southwestern New York. It also reaches or closely approaches the limits of glaciation in eastern Ohio and the western edge of Pennsylvania. But elsewhere in the region under discussion the border of the Wisconsin drift lies some distance back from the glacial boundary. In southeastern Indiana it falls short 50 to 60 miles, and in southwestern Ohio 10 to 40 miles, as may be seen by reference to Pl. II.

The late Wisconsin drift seems to reach about to the border of the early Wisconsin, and possibly in places beyond it, in central and eastern Ohio and in northwestern Pennsylvania. But in southwestern Ohio and southeastern Indiana, as indicated in Pl. II, the early Wisconsin drift has a marked extension beyond the late Wisconsin. The time relations of the Wisconsin drift in the district east from the reentrant angle in southwestern New York have not been fully settled. It remains to be determined whether

the border of the late Wisconsin swings southeastward with the glacial boundary or takes an eastward course toward the southern ends of the Finger Lakes, leaving a strip of early Wisconsin drift exposed in northern Pennsylvania and the adjacent portion of New York.

In the vicinity of the reentrant angle in southwestern New York the border of the Wisconsin drift is very attenuated on the uplands and somewhat difficult to locate, but in the valleys it is marked by morainic ridges and knolls of considerable strength. The influence of topography has been very marked, there being pronounced lobation in the valleys and lowlands, and a falling back or northward recession of the border on the uplands. This is well shown in the map of the Olean quadrangle (Pl. IV). How far eastward these characteristics of the Wisconsin drift border extend has not been determined. They are known to prevail at least to the point where the glacial boundary passes into Pennsylvania, and they may be prevalent over the crest of the Allegheny Mountains.

From the reentrant angle in New York southwestward the Wisconsin drift presents a definite terminal moraine on high uplands as well as in valleys. The sinuosities of its border are also far less striking than in the vicinity of the reentrant angle. It exhibits pronounced lobation in the broad lowlands, such as the Grand River, Scioto, and Miami basins, but the ordinary valleys of the hilly country were occupied only a very short distance beyond the position of the border on neighboring ridges.

There is a well-defined terminal ridge or moraine marking the border of the early Wisconsin drift in Ohio and Indiana as well as that of the late Wisconsin drift. It is therefore only on elevated uplands in the hilly country of southwestern New York and northern Pennsylvania that the border of the Wisconsin drift is not marked by a definite ridge. The terminal ridge or moraine is a far more conspicuous feature of the Wisconsin glaciation than of any earlier glaciations, not only in the region under discussion but throughout the glaciated portion of the United States.

CHAPTER V.

THE OLDEST DRIFT (KANSAN OR PRE-KANSAN).

GENERAL STATEMENT.

It was noted by Lewis and Wright, while tracing the drift border across Pennsylvania, that a deposit of drift is present in northwestern Pennsylvania outside the bulky moraine that they were tracing, a moraine which has proved to be of Wisconsin age. They called this outlying drift a "fringe," and supposed it to be a dependency of the moraine.[1] It was also noted by Wright that in eastern Ohio there is an outlying sheet of drift, and this, too, was called a fringe.[2] This peculiarity of the drift margin in eastern Ohio had previously been noted by Chamberlin, who raised the question whether the border drift was contemporaneous with or older than the moraine.[3] A few years later he investigated the outlying drift of western Pennsylvania and reached the conclusion that it is much older than the moraine back of it.[4] The writer's studies have served to bring into clearer recognition the evidence that the outlying drift of western Pennsylvania is far older than the Wisconsin drift. The extent or limits of this drift sheet having been considered in the preceding chapter, we may pass at once to the description of the deposit.

DESCRIPTION OF THE DRIFT.

This old drift generally contains a large number of waterworn pebbles, with which so little clay is found that well drillers commonly call the deposit gravel. The bedding, however, is very indistinct and the assorting imperfect, so that it seems appropriate to call it a very stony till rather than

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[1] Second Geol. Survey Pennsylvania, Report Z, 1884, pp. 45, 170, 171, 177, 179–181, 186, 195, 200–202.

[2] Op. cit., pp. 206–207; see also Glacial Boundary in Ohio, p. 35.

[3] Am. Jour. Sci., 3d series, Vol. XXIV, 1882, p. 96.

[4] Bull. U. S. Geol. Survey No. 58, 1890, pp. 14–15; see also Am. Jour. Sci., 3d series, Vol. XLVII, 1894, pp. 272–273.

a gravel. In valleys which discharged toward the ice margin and had their lower courses obstructed by the ice sheet a large amount of silt or fine sand is found under drift which was deposited directly by the ice sheet. This is notably the case in the old valley that leads northward from the bend of the Tionesta to the Allegheny. Carll reports that the filling to a depth of over 200 feet is chiefly clay, and that only the surface carries large stones of northern derivation.[1] Several valleys lying within the limits of the Wisconsin drift show a great amount of fine material under the stony drift, and this, as in valleys outside the limits of the Wisconsin, was probably deposited before the first ice invasion or contemporaneously with it.

In the portion of the Allegheny Valley which was either covered or closely bordered by the ice sheet, viz, that from Warren down to Kennerdell, stream action was probably interrupted or more or less intermittent. As a result there is on the whole a less uniform and less clearly assorted deposit than in the portion below Kennerdell, which was not obstructed by the ice sheet. Portions of it, however, are as well assorted as in the terraces outside the limits of glaciation.

The bowlders found in this old drift are remarkably small, it being rare to find one that exceeds 2 feet in diameter, while the great majority are less than 1 foot. Many of them are of a red granite which has become so decayed that a single blow with a hammer will knock the rock to pieces. Both in size and in state of decay they are strikingly in contrast with the bowlders found on the Wisconsin drift, there being many large and fresh-looking bowlders in that drift. The rocks contained in this old drift, and also those in the Wisconsin drift of northwestern Pennsylvania, are very largely derived from the Devonian and Carboniferous rocks of that region. Apparently less than 1 per cent of the coarse rock ingredients has been derived from the region beyond Lake Erie.

The state of decay of the local as well as of the foreign stones in this old drift, and also the great amount of erosion it has sustained, put it in striking contrast with the fresh-looking and but slightly eroded Wisconsin drift. Nearly all the pebbles found on the surface of the old drift have become so deeply weathered that it is often necessary to break them in order to obtain a sufficiently fresh surface to warrant classification. On the surface of the Wisconsin drift the same classes of pebbles are still so

[1] Second Geol. Survey Pennsylvania, Rept. I^4, p. 353.

fresh that only a glance is necessary to determine their class. As the upland portion of this old drift is a thin deposit, it is usually deeply weathered from top to bottom. In the valley portion weathering is very pronounced to a depth of 20 feet or more. Usually the weathering extends to the bottom of the coarse surface portion.

Striated stones are common in the upland drift, and a few have been found in the drift along the valleys. The markings are rather indistinct because of weathering, and contrast strongly with the fresh lines to be seen on rocks belonging to the Wisconsin drift.

The records of a few well borings and some detailed observations are here given, which throw light upon the thickness and structure of drift in a few of the valleys.

At Clarendon, near the present divide in the lowland that connects the headwater portion of the Tionesta with the Allegheny, one well is reported to have reached a depth of 240 feet below the level of the railway station before entering rock. There were thin beds of stony clay and gravelly material interbedded with heavy deposits of blue silt. Some wells in the village enter rock at much less depth, but they are near the border of the old valley. On the borders of the valley, in the vicinity of Clarendon, glacial deposits occur up to a level fully 100 feet above the railway station, or 1,500 feet above tide. These deposits on the border of the valley are coarser than those below the level of the railway station; they include considerable cobble and coarse gravel, but they contain only small bowlders, none being observed which exceed 7 inches in diameter. The Canadian rocks are so rare that search is often necessary to discover them.

On the east side of the Conewango River, opposite Warren, very stony or gravelly drift abounds up to fully 1,400 feet above tide, or to about 250 feet above the river. Wells indicate that the depth near the valley border is often more than 100 feet, and it is probable that the middle of the valley received a filling of nearly 300 feet. Only narrow remnants are preserved on the valley borders, and these consist largely of gravel or very stony drift.

In the valley bottoms near Warren there is a gravel deposit of Wisconsin age, connecting with the moraine a few miles north of Warren, which is composed of markedly fresher material than that at high levels on the valley borders. The old gravel appears also to underlie the Wisconsin. About 1½ miles below Warren, on the south side of the Allegheny, there is

an exposure showing the fresh Wisconsin gravel resting on the deeply stained and weathered gravel of the old drift.

Between Warren and Tidioute there is but a small amount of old drift preserved on the valley borders, and wells in the bottoms indicate that the rock floor is but 25 to 40 feet below the stream. The gravel in the valley bottoms is largely of Wisconsin age.

In this connection it may be remarked that from Warren down to the mouth of the Allegheny the rock floor is usually within 25 feet of the present stream, and it is not known to lie more than 50 feet below the stream at any point. It thus contrasts strongly with the part of the valley in New York whose rock floor slopes toward the Lake Erie Basin and lies 200 to 300 feet or more below the stream. The chief northern tributaries of the Allegheny also have a large amount of drift in their headwater portions and rock floors sloping toward the Lake Erie Basin. These features are discussed in Chapter III.

At Tidioute there are rock shelves on each side of the Allegheny that carry 80 to 100 feet of old drift, giving the appearance of terraces with an elevation of about 150 feet above the river. The drift appears to be largely gravel. A stony drift is found on the slopes of the valley above and also opposite Tidioute up to a height of about 330 feet above the stream, or 1,420 feet above tide, but none was noted at higher levels. Whether the valley was once filled to the upper limit of this drift is not clear. The glacial boundary may extend to the Allegheny at Tidioute. Three miles west of Tidioute, near McGraw post-office, on uplands standing 500 feet or more above the Allegheny, thin deposits of drift occur, and notable deposits occur at about the same distance northwest of Tidioute on the headwaters of East Pine Creek and on Gordon Run.

At Trunkeyville, on the Allegheny, a few miles below Tidioute, a granite bowlder a foot in diameter was noted on a rock shelf at about 150 feet above river level, but no other evidences of glaciation were noted at that place. Possibly it was transported down the valley by the stream, as there are occasional remnants of gravel at levels even higher than the bowlder in that part of the valley. At Hickory, the next village below Trunkeyville, waterworn pebbles abound on a rock shelf standing about 200 feet above the river.

In the vicinity of the bend near President the Allegheny Valley is

again bordered by drift deposits at high altitudes. The rock shelves up to a height of 150 feet above the river carry gravel deposits containing Canadian rocks, which in places have a known depth of 30 to 40 feet. The slopes and shelves up to a height of fully 300 feet above the river carry scattering pebbles, among which an occasional Canadian rock is found. It is not certain that the glacial boundary lies as far southeast as President, no drift having been observed by the writer on the uplands in that vicinity, but the high altitude of these glacial pebbles suggest ice occupancy. Undoubted glacial deposits are found about 5 miles west of President, on uplands bordering the Allegheny, at an altitude of more than 400 feet above the stream.

At Walnut Bend a rock shelf or point encircled by the Allegheny River has received a heavy deposit of glacial gravel, one well indicating a depth of 135 feet. The gravel exposed on the slopes is rather fine, pebbles exceeding an inch in diameter being rare. The top of this gravel deposit stands, by aneroid, about 250 feet above the river.

Above Oil City gravel appears on the slope north of the Allegheny up to an altitude of fully 250 feet above the stream. It seems to have a depth of 100 feet or more as exposed in gullies which cut down through it. South of Oil City rounded pebbles, including an occasional Canadian bowlder, appear on slopes up to a height of more than 300 feet above the stream. It is thought, as indicated above, that the ice sheet covered the Allegheny Valley in that vicinity. A rock shelf on the south side of the river is shown by a well to carry 90 feet of drift. The well mouth is about 220 feet (aneroid) above river level.

At Reno, about 3 miles below Oil City, several wells show a large amount of drift on high shelves. One, on ground 265 feet above the river, penetrated 132 feet of drift; one, on ground 30 feet lower, 122 feet; and one, at an altitude of 200 feet above the river, 142 feet. This drift is described as being a sandy gravel, and slight exposures indicate that it may be a stream deposit. If so, the valley may once have been filled to the level of the highest well, 265 feet above the present river level.

An abandoned channel in the northeastern part of Franklin, discussed in Chapter III and shown in Pl. VIII, received a large amount of drift, which from well records appears to be of finer texture than that commonly displayed in the Allegheny Valley, much of it being sand. The surface portion, how-

ever, contains cobblestones and bowlders. The thickest section of drift in this channel yet reported is in a water well at the residence of George Mason, which reached a depth of 113 feet without entering rock. The well is on ground about 1,125 feet above tide, or 165 feet above the Allegheny River at Franklin.

Between Franklin and Brandon very little drift appears in the Allegheny Valley, though uplands immediately west and south of Franklin carry glacial deposits at an altitude of fully 500 feet above the stream. A road grading on the slope of "Bunker Hill," 2 miles west of Franklin, shows 2 to 5 feet of stony glacial drift, including a few Canadian bowlders, at an altitude of 500 to 540 feet, by aneroid, above the river. Exposures of similar character were noted on another ridge a mile farther west. There are also thin deposits at about as high altitude near the "Twin Churches," 2 miles south of Franklin. An occasional bowlder is found at nearly as high altitudes on the east side of the Allegheny near Franklin.

At Brandon, 11 miles below Franklin, drift deposits are better displayed on the east side of the valley than at points near Franklin, there being a nearly continuous thin sheet of drift on the slope for a mile east of Brandon, extending up to a level of about 500 feet above the stream. Canadian rocks were noted at frequent intervals in the lower 300 feet, but above this level none were found. The rocks farther up the slope are chiefly local sandstones, most of which are well rounded. Two miles below Brandon gravelly drift appears on the east bluff to a height of fully 300 feet above the river, and it appears at even higher altitudes back of Kennerdell, the aneroid indicating 360 feet above the river. Near Rockland, 8 miles below Kennerdell, gravelly deposits cover the slope up to an altitude of 320 feet (aneroid) above the river. It seems probable that the valley in the region between Kennerdell and Rockland was filled to the level of the gravel deposits by an outwash from the ice sheet rather than by direct glacial deposition. The glacial boundary, as indicated above, appears to lead southwestward from near Kennerdell directly away from the Allegheny Valley. The deposits farther down the Allegheny are discussed below in connection with glacial outwash.

Returning up the Allegheny Valley to the mouth of Brokenstraw Creek, about 6 miles below Warren, we find leading in from the west a valley which is broader than the valley occupied by the Allegheny below that point.

As shown in Chapter III, it probably constituted the main western tributary of the old Upper Allegheny. For a few miles west of the Allegheny there is an open valley with low terraces of Wisconsin gravel standing only a few feet above Brokenstraw Creek. On its borders there are rock shelves carrying patches of gravel connected with the old drift, such as appear along the Allegheny. The uplands north of Brokenstraw Creek, and also uplands farther east along the north side of the Allegheny, are covered with a thin but nearly continuous sheet of very stony drift, including a liberal supply of small bowlders. These deposits have been noted at altitudes 600 feet or more above the valleys, or fully 1,800 feet above tide. South of Brokenstraw Valley, from its mouth up to Garland, there seems to be very little upland drift, and it is possible that a small unglaciated tract appears between this valley and the Allegheny.

From Garland southwestward to Titusville there is a lowland known as Grand Valley, which is filled deeply with drift. It is not certain that it was drained by a single stream. On the whole it seems more probable, as noted in Chapter III, that the northeastern end discharged eastward to the old Upper Allegheny, and the southwestern end westward, past Titusville, to the old Muddy Creek. The old divide may be buried to a depth of 200 feet. At Newton, which stands near the present divide in this lowland, a well penetrated 283 feet of gravelly drift and entered rock at about 1,125 feet above tide, which is slightly above the level of the rock floor of the Allegheny a few miles to the east. At Grand Valley station a well reached rock at 204 feet, the altitude of the rock floor there being about 1,140 feet above tide. A well 1 mile southwest of Grand Valley penetrated 220 feet of drift, reaching rock at a level scarcely more than 1,100 feet above tide. About 3 miles east of Titusville drift deposits are heavy on the south border of this valley. One well on ground about 350 feet higher than Titusville, or 1,550 feet above tide, reached a depth of 235 feet without entering rock. The lowland in that vicinity was so nearly filled with drift that the present drainage line, Pine Creek, departs from the old line and cuts across the face of the old north bluff.

On the south side of Grand Valley drift deposits are heavy along the line of old valleys to their heads, but seem to be light on the intervening uplands. The wells in these valleys often pass through 100 feet or more of drift within a mile north of their heads, at altitudes of 1,600 to 1,700 feet

or more above tide. The amount of drift is meager, both on uplands and in valleys, south of the divide which limits the Grand Valley drainage. In a few places well-defined channels underlain by gravel cross the divide and afford evidence of the discharge of glacial waters across it.

Along Oil Creek Valley from Titusville to Oil City there are several exposures of the old drift on the face of the bluffs, but the valley bottom appears to be underlain by gravel of Wisconsin age which connects with the outer Wisconsin moraine a short distance from Titusville.

The valley of Sugar Creek is bordered in a similar manner by deposits of old drift, while the Wisconsin drift covers the valley bottom. The tributaries of Sugar Creek which lie outside of the limits or influence of the Wisconsin glaciation carry only deposits of the old drift. These deposits are shown by wells to reach a depth of 100 feet or more. The material is very stony, so that it is commonly classed as gravel, but the writer found here, as well as in many other localities, a slight clay admixture and also angular striated stones with the well-rounded stones.

A heavy deposit of old drift is found in the abandoned valley that leads from Sandy Creek at Polk northward to French Creek. This deposit is exposed at the north end in the bluff of French Creek, and also in ravines immediately south of French Creek. There is some blue silt in the lower part, which was probably deposited in advance of the ice sheet. The surface portion is a stony drift similar to that found so widely in this region.

AMOUNT OF EROSION.

In addition to the evidence of great age found in the advanced stage of weathering of the pebbles, there is the evidence from erosion. As indicated in the description of the drift, there are several valleys in which the drift is preserved only in narrow strips in recesses or places along the valley borders where erosion is at a minimum. The distribution of these strips is such as to indicate that they are remnants of a sheet which once filled the valleys nearly if not quite to the height at which they occur. This is very clearly shown in the portions of old valleys which have been abandoned. The abandoned Grand Valley, which connects Brokenstraw and Oil creeks, has a filling of drift 200 to 300 feet in depth occupying its entire width. But Oil and Brokenstraw valleys, which, apparently, received a similar filling, now carry only narrow strips in recesses along their borders.

The Conewango Valley also carries only narrow strips of a filling which reached to a height of about 250 feet above the stream.

It is probable that much if not all of the Allegheny Valley from Warren down to the mouth of the Clarion was filled to a height of 150 to 200 feet above the present river level. But now there are only a few remnants to indicate the height to which it was filled. It may be considered doubtful whether the Allegheny was greatly filled; but the fact that a large amount of glacial material was carried by stream action from the middle or glaciated portion of the Allegheny into the lower or unglaciated portion at levels more than 200 feet above the present stream seems to demand a great filling of the glaciated portion. It is hardly probable that an ice sheet would fail to make heavy deposits in a valley which it partially covered and with which it had numerous connections, when it was able to contribute enough material to a larger valley (the Lower Allegheny) leading away from the ice margin to produce a filling 80 to 100 feet in depth for a distance of more than 100 miles.

It seems well within bounds to estimate that the erosion of this old drift on the principal tributaries of the Allegheny which carry it—Conewango, Brokenstraw, Oil, and French creeks—as well as on the Allegheny itself, reached a depth of 150 to 200 feet and a breadth nearly as great as that of their valleys.

It seems probable also that the attenuated character and patchy distribution of the upland drift has been to a marked degree intensified by erosion. It would be difficult, however, to make any estimate of the erosion there, since the original amount of drift can scarcely be estimated or even closely conjectured.

The valleys just mentioned have afforded discharge for the waters of later glacial stages than the one under consideration, and this should not be overlooked in dealing with the amount of erosion, nor should the effect of the glacial floods that occupied the valleys during the melting of the earliest ice field be disregarded. While in general the glacial floods are depositing rather than eroding agencies, not a few instances can be cited where streams which headed in the ice sheet have cut conspicuous trenches across gravel plains that had just been built as outwash aprons along the ice border. But where such marked trenching has occurred the glacial streams were apparently favored by a good gradient, such as is so often afforded by

the rapid slopes of the outwash aprons. There seems to be a case of such erosion by glacial floods in the trench above noted, which was cut in the old drift at Clarendon to a depth of 100 feet and opened southward into the Tionesta Valley. This is out of the reach of stream action in later stages of glaciation and apparently seems referable only to the work of a glacial stream connected with the earliest ice-invasion.

But conditions for erosion of this sort seem not to have been open to any great extent on the Allegheny or its main tributaries at the time of the first ice invasion. The trenching in general must have kept pace with the slow deepening of the Lower Allegheny and Ohio valleys which followed the filling with the gravel of this earliest glacial stage. The floods connected with the earliest stage of glaciation would probably effect scarcely more than the reduction of the upper part of the Allegheny to a gradient in harmony with the contemporaneous gradation plain of the Lower Allegheny, whose height after this gravel filling occurred was, as already shown, nearly 300 feet above the present stream.

What proportion of the erosion, both of the rock and of the drift, on the Allegheny and its main tributaries is referable to glacial streams in connection with later ice advances will be difficult to determine. It may perhaps be determined by a careful comparison of work done by eastern and southern tributaries which have not been aided by glacial floods with that done in the glaciated tributaries which were thus aided. Such a comparison has not been attempted, but it is apparent from a merely casual observation that the streams which have been unaided by glacial floods have nevertheless opened valleys of sufficient size to warrant the inference that glacial floods are responsible for only a minor part of the erosion displayed by the glaciated tributaries.

CHARACTER OF THE OUTWASH.

An outwash of gravel and sand appears in such portions of the Allegheny River and some of the tributaries as were not obstructed by the ice sheet, but were instead favorably situated for receiving it. It was distributed far down the valleys, reaching even into the upper part of the Ohio Valley. The western tributaries of the Allegheny, as far down as the glacial boundary near Kennerdell, were largely covered by the ice sheet, but seem to have been utilized as lines of discharge for glacial waters as the ice melted.

The glacial waters usually found exit into valleys that were only 200 to 300 feet above the Allegheny, but a few points were found where the discharge took place at much higher altitude. Thus at the head of Gordon Run, a tributary which enters the Allegheny at Tidioute, a line of glacial discharge has formed a flat-bottomed channel at a height of 1,750 feet above tide, or more than 600 feet above the river. There is a much lower tract to the north which must have been covered by the ice sheet at the time waters were discharged into Gordon Run. A neighboring valley, Perry Magee Run, received glacial waters at about as high an altitude as Gordon Run. The headwaters of Pithole Creek also received glacial waters while the ice was occupying the lowland to the north. The altitude of this stream is but little lower than of the tributaries just mentioned.

There seems to have been but one eastern tributary of the Allegheny which received a glacial outwash, Tionesta Valley. The outwash in this valley will be considered first, after which that in the Lower Allegheny, the Beaver, and the Upper Ohio will be taken up. Possible lines of discharge in southwestern New York during this ice invasion are discussed to better advantage in connection with the terraces of Wisconsin age.

TIONESTA VALLEY.

From Clarendon, near the bend of the Tionesta, a stream of considerable volume and strength must have discharged from the ice sheet into the lower Tionesta Valley. A channel one-fourth to one-half mile in width passes from the present divide southward to the bend of the Tionesta, on the borders of which the glacial deposits rise in places to a height of 100 feet above its swampy bottom. This channel stands about 1,400 feet above tide, or 225 feet above the Allegheny River. It falls nearly 60 feet in 5 miles to Sheffield. Below this village, as noted in Chapter III, an old divide is crossed by the Tionesta, and the valley for several miles is very narrow and carries but little glacial outwash. The writer's observations were extended only 3 or 4 miles below Sheffield, but Wright has followed the valley down to its mouth and reports the occurrence of glacial gravel in small amount at a few points in its lower course. N. P. Wheeler, of Tidioute, reports that just back of Newtown Mills, a few miles above the mouth of the Tionesta River, there is a terrace of glacial gravel which stands about 100 feet above the stream, or 1,250 feet above tide. Wheeler estimates the width of the terrace to be one-eighth of a mile or

more, and he thinks the gravel extends to the stream level. Pebbles of granite 2 to 2½ inches in diameter, collected by Wheeler on this terrace, were inspected by the writer.

From the available data it appears that the stream along the Tionesta had sufficient strength to carry gravel down nearly if not quite to the Allegheny Valley. Possibly a large filling occurred, which has since been almost entirely removed. In support of this view the deposit at Newtown Mills may be cited. The amount of channeling in the gravel near the bend of the Tionesta also indicates that considerable material was carried down the Tionesta.

LOWER ALLEGHENY VALLEY.

The Upper Allegheny, as above noted, appears to have had points of special filling, as at Tidioute and near Oil City, between which were long stretches in which the amount of filling may have been less. Upon turning to the Lower Allegheny a very different condition is found. The valley there has been filled up with sand and gravel to an even grade, harmonizing in slope with that of the present stream, but 250 feet or more above it. Below the mouth of the Clarion the Allegheny has a well-defined ancient gradation plain, which has been trenched by the river to a depth of 200 feet or more, as indicated in Chapter III. The gravel covers this old gradation plain to an average depth of perhaps 80 feet. In places it extends 50 to 100 feet below the gradation plain, as if either that amount of trenching of the old valley floor had preceded the gravel deposition or a secondary filling had taken place during a subsequent excavation. But, as already shown (Chapter III), the trenching appears not to have been completed until an interglacial stage subsequent to this early gravel deposition.

From the mouth of the Clarion up to the point where the glacial boundary bears away from the Allegheny (near Kennerdell) the Allegheny Valley is very narrow, being about the width of the inner valley below the mouth of the Clarion. It carries only occasional remnants of gravel outwash, yet it can scarcely be doubted that there was a filling to correspond with that on the Lower Allegheny. Some of the remnants stand at a sufficiently high altitude to clearly support this view.

Since the deposition of the gravel so much erosion has occurred on the gradation plain of the Lower Allegheny that the original surface of the gravel is preserved in only a few places. In several places the gravel deposits

have been cut into benches or terraces with a uniform level, and these reductions from the original level of filling may easily be mistaken for it.

The table below presents several points at which it is thought that the altitude of the original surface of the gravel has been determined. The table also includes points along the Ohio.

Table showing the upper limit of gravel filling in the Lower Allegheny and Upper Ohio valleys.

Location.	Approximate distance from glacial border.	Altitude above stream.	Altitude above tide.
PENNSYLVANIA.	*Miles.*	*Feet.*	*Feet.*
Kennerdell	0	360	1,270
Rockland	8	320	1,210
Foxburg	21	275	1,135
Monterey	28	280	1,125
East Brady	38	290	1,115
Red Bank	43	280	1,100
Templeton	53	255	1,050
Kittanning	62	250	1,030
Ford	67	255	1,020
Arnold	87	285	1,011
Allegheny	107	285	980
Beaver	*a*132	320	980
OHIO.			
Toronto	*a*167	320	950

a This represents the distance along the Allegheny; the distance along the Beaver is much less.

The origin or mode of formation of these terraces has been a subject of much discussion. At the time the hypothesis of an ice dam at Cincinnati was suggested by Wright[1] these terraces were cited by Lesley[2] and corresponding terraces on the Monongahela were cited by White[3] in support of the hypothesis. But prior to that time Stevenson[4] had interpreted those on the Monongahela and Chance[5] those on the Allegheny to be river terraces.

[1] G. F. Wright: Proc. Am. Assoc. Adv. Sci., Vol. XXXII, 1883, p. 207; Science, Vol. II, 1883, p. 664; Am. Naturalist, Vol. XVIII, 1884, pp. 563–567.

[2] J. P. Lesley: Science, Vol. II, 1883, p. 436; Second Geol. Survey Pennsylvania, Rept. Z, 1884, pp. viii–xi.

[3] I. C. White: Proc. Am. Assoc. Adv. Sci., Vol. XXXII, 1883, pp. 212–213.

[4] J. J. Stevenson: Second Geol. Survey Pennsylvania, Rept. K, 1876, pp. 1–22; Proc. Am. Philos. Soc., Vol. XVIII, 1880, pp. 289–316.

[5] H. M. Chance: Second Geol. Survey Pennsylvania, Rept. V^2, 1880, pp. ix–x, 17–22.

In view of these differences of interpretation Chamberlin and Gilbert made a special study of the terraces on the Allegheny and Monongahela, the results of which have been presented by Chamberlin in a bulletin of this survey.[1] In this bulletin it was shown (*a*) that the terraces slope with the present stream, (*b*) that the material capping the terraces is distinctly fluvial, (*c*) that the terraces have rock platforms which demand more work than could result from the action of waves in a narrow lake, (*d*) that the form and distribution of the terraces are of the fluvial, not lacustrine order, (*e*) that abandoned channels and oxbows have been preserved in connection with the terraces. The view that the terraces were produced by a lake held in these valleys by an ice dam at Cincinnati seems, therefore, completely set aside by these observations.

The degree of preservation of the gravel on the high terraces presents a striking contrast to that of the gravel of Wisconsin age found low down in the Allegheny Valley. It is far more deeply stained and rotten, the difference being as striking as in the respective drift sheets. It also differs from the later gravel in carrying a much smaller proportion of Canadian rocks. Search is often necessary to discover a Canadian pebble in the old gravel, while in the later or Wisconsin gravel the Canadian rocks are a conspicuous ingredient.

The old gravel is generally fine, and contains a large admixture of sand, while in places it is interbedded with deposits of clear sand; but, as is natural in river deposits, it also contains a few large stones 1 to 2 feet or more in diameter. These stones are chiefly local sandstones washed in from neighboring bluffs, though occasionally a large Canadian rock is found.

A few detailed observations concerning these deposits and the features along the Lower Allegheny will serve to illustrate the above statements.

As indicated above, the Allegheny Valley is narrow from Kennerdell to the mouth of the Clarion, and but a small amount of gravel remains in it. These remnants are in every observed case situated on sloping points on the inner curve of sharp bends in the river, and have been cited by Wright as evidence that the valley was excavated to about its present depth prior to the gravel deposition.[2] The writer is in agreement with Wright in the

[1] T. C. Chamberlin: Bull. U. S. Geol. Survey No. 58, 1890, pp. 24–32.
[2] Am. Jour. Sci., 3d series, Vol. XLVII, 1894, p. 175.

view that the occurrence of the gravel at low levels can not, in some cases at least, be accounted for by creeping or by landslides; but since a stream is liable in such places to redeposit material on its inner curve during the deepening of the valley, the writer considers it probable that the gravel has been carried by the river to lower levels than its original position. The original depth can as yet scarcely be determined on its own inherent evidence, and the precise extent of the excavation in that part of the valley prior to the gravel deposition may be regarded as uncertain, except as correlated conditions throw light upon it.

Opposite the mouth of the Clarion, on the west side of the Allegheny, there is a recess in the valley wall which carries a deep and extensive deposit of gravel, with an upper limit about 275 feet above the river. There is probably an area of 80 acres with an average depth of 100 feet of gravel. Across it there passes an old channel of the river whose bed is about 250 feet above the present stream. Just east of it is another flat-topped terrace, apparently a reduction from the higher terrace, with an altitude scarcely 200 feet above the river. In both terraces the pebbles are fine, mainly an inch or less in diameter, and include a very few Canadian rocks.

From this recess on the west side the stream appears to have passed eastward across the Allegheny Valley and filled the valley to about the level of an oxbow-like channel east of Parker, brought to notice by Chance.[1] This so-called oxbow, however, stands somewhat higher than the broad gradation plain of the Clarion–Lower Allegheny, and has a channel much narrower than that of neighboring portions of the valleys of these streams. The view that it is an old oxbow of either of these streams has recently been called in question by E. H. Williams[2] and an alternative view suggested. This later view is one which the writer considers more consistent with the features than the one presented by Chance. It refers the opening of the double channel resembling the forks of an oxbow to a shifting of a small tributary of the Allegheny from one side to the other of a low hill that stood nearly opposite the point at which the tributary entered the valley. At the time of the gravel deposition under consideration, this small oxbow-like channel became partially filled; but, as noted by Wright,[3] there was not

[1] H. M. Chance: Second Geol. Survey Pennsylvania, Rept. V^2, 1880, pp. 17–22.

[2] At Albany meeting of Geological Society of America, Dec., 1900.

[3] Am. Jour. Sci., 3d series, Vol. XLVII, 1894, pp. 173–175.

a sufficiently strong current through it to carry gravel completely around the loop. There is gravel on the north side and eastern end, but much of the south side appears not to have been filled. Gravel was carried a short distance into the southern limb or branch by a current which passed down the Allegheny but which did not pass around the oxbow. Between this filling and the filling of the eastern end there is an unfilled space about a half mile in length. The filling at the eastern end is mainly sand, the gravel being deposited nearer the river. The upper limit of gravel in this oxbow-like channel seems to be about 250 feet above the river, or somewhat lower than at points on the Allegheny immediately above and below. This is to be expected if it carried only a weak and indirect current.

From the south end of this oxbow-like double channel the gravel deposits were carried into a recess on the west side of the valley below Parker, but only a small remnant is there preserved. The next extensive remnant is found on the east side immediately north of Monterey. The gravel there has an estimated thickness of 125 feet, its upper limit being about 280 feet above the river and the underlying rock shelf about 155 feet. Only a small part remains at the original level.

Between Monterey and Bradys Bend there are terraces standing considerably below the level of the terraces at Monterey, which are probably reductions from the original level of filling. The broadest ones are scarcely 200 feet above the river.

Around Bradys Bend the gravel deposits have apparently been carried down the slope with the downward and outward cutting of the stream, so that the lower limits of the original deposition are hard to determine. In the southern part of East Brady, at an altitude of about 120 feet above the river, gravel appears in considerable depth, and may not have been redeposited. At lower levels it is strewn on the slope and probably has been redeposited. South of East Brady, over the ridge which the river encircles, waterworn and angular material is found embedded in a reddish sand up to levels nearly 300 feet above the river, but it is not certain that these highest deposits contain glacial material. On the south side of the ridge an island-like gravel remnant is preserved, at an altitude about 270 feet above the river, which stands on a rock shelf 40 feet lower, or 230 feet above river level. No Canadian rocks were found in this gravel island, but the general aspect of the gravel is similar to that in the glacial deposits just described, a few miles up the valley.

South of Red Bank Junction, on the west side of the river, a narrow remnant of a terrace was found about 280 feet above the river, which also may be glacial, though Canadian rocks were not found in it.

Opposite Templeton, on the west side of the river, a glacial terrace, with coarse gravel containing a few Canadian rocks, has an altitude of about 250 feet above the river. Rounded pebbles occur on the slope above this terrace up to a level about 50 feet higher.

Between Templeton and Kittanning there are several remnants of a deposit of glacial gravel standing about 250 feet above the river, as well as terrace-like remnants at lower altitudes, apparently reduced from the original level of filling. The rock shelves on which the gravel rests stand only 150 to 200 feet above the river. The original depth of the gravel was probably 75 feet or more.

West of Kittanning there is a deposit of glacial gravel, standing about 250 feet above the river, in which wells have reached a depth of 30 feet without entering rock. A mile south of Kittanning, at a similar altitude, wells reach a depth of 40 feet in gravel. A short distance farther south, on the south side of Garretts Run, the thickness of the gravel is 70 feet or more. It contains coarse beds and includes a few Canadian rocks (granite and quartzite). This deposit has an altitude of about 235 feet (aneroid) above the river. On a continuation of this deposit immediately back of Ford a channel was found along its east border next the bluff, which seems to have been made by a stream. It is much narrower than the present river channel, being only 50 to 75 yards in width, and probably carried only a part of the old river. Notwithstanding its great altitude above the present river, the banks of the channel are clearly defined. The terrace here is probably reduced from the original level of the gravel filling, for pebbles appear on the slope back of it up to a level about 20 feet above the terrace or 255 feet above the river.

On the west side of the river an old oxbow channel is found east of North Buffalo at an altitude only 120 feet above the river. It is in a terrace which stands 30 to 40 feet higher, but the terrace, as well as the channel, is evidently far below the original level of gravel filling. There are extensive terrace remnants on the west side below North Buffalo, but they all seem to be cut down below the original level. On the east side, also, there has been much reduction from the original level, though small

remnants of the gravel were found east of Logansport and back of White Rock at an altitude of about 220 feet above the river.

On the west side, near Natrona, there is one of the most extensive terrace remnants on the river, fully a square mile being preserved at an altitude of about 250 feet above the stream. Jillson has determined the altitude by Locke level and found it to be 953 feet above tide at the reservoir and 963 feet at the fair grounds.[1] This may have been reduced about 50 feet from the original level, as indicated by deposits at Arnold, discussed below. The surface portion to a depth of several feet is mainly sand, but at greater depths fine gravel occurs. The gravel has a depth of more than 50 feet and may in places reach 100 feet.

An extensive remnant of gravel filling is found on the east side of the Allegheny below Natrona, near Arnold and Kensington stations. It borders the river for a distance of nearly 3 miles. Just east of Arnold gravel is found up to an altitude about 200 feet above the station, or 1,000 feet above tide. Jillson has determined its altitude by Locke level to be 1,011 feet above tide. There is an island-like hill with this altitude bordered by a terrace 60 to 65 feet lower. An old weather-stained gravel covers the slope from this terrace down to the level of the railway station, about 800 feet above tide, where the Wisconsin gravel sets in. If the valley trenching had reached down to the level of the railway station before the first gravel filling occurred, a filling of 200 feet would have been required in the deepest part of the trench to build it up to the level of the island-like knoll. This is, however, one of the cases in which the relation of the gravel to valley trenching could not be clearly made out.

The gravel appears on the west side of the river below Kensington, and is preserved in a terrace remnant, about 2 miles in length, back of Springdale and Acmaton. The altitude of the upper terrace, as determined by Jillson, is 954 feet above tide at Springdale and 948 feet at Acmaton.

[1] The late Dr. B. C. Jillson, of Pittsburg, made many accurate determinations of the altitudes of terraces and rock shelves in the vicinity of that city on the Allegheny, Monongahela, and Ohio rivers, which have been published by the Pittsburg Academy of Science, in a pamphlet of 25 pages issued in December, 1893, and entitled "River Terraces in and near Pittsburg." It should perhaps be explained that the writer's studies preceded the publication of this pamphlet and were carried on without the knowledge of Jillson's work. The studies were entirely independent of each other, yet the interpretations are in essential harmony so far as the old or high-level gravels are concerned. The title of Jillson's paper, as well as his discussion, indicates that he recognized the deposits to be the product of a stream.

The breadth is in places fully a half mile. It is covered to considerable depth with sand and gravel.

Below Acmaton the gravel terrace appears on the east side and is well displayed from Panther to Verona, a distance of 3 miles. In places the width is nearly a mile. The altitude as determined by Jillson is about 965 feet above tide, but the writer found places where it rises to nearly 1,000 feet. Wells 30 feet in depth do not reach the bottom of the gravel. In places there is considerable sand. An old channel of the river, standing about 250 feet above the present stream, connects on the south with the Allegheny at Verona and on the north with the valley about 1½ miles above Verona. It passes back of hills that stand perhaps 400 feet above the river. It seems to have been occupied by the river after the deposition of the old or high-level gravel, for this gravel rises in that vicinity to a higher level than the channel.

Below Verona the gravel appears on the west side and is well displayed back of Claremount at an altitude of about 250 feet above the river (Jillson). It has in places a width of about one-half mile. It contains considerable coarse gravel and cobble. From Claremount down to the mouth of the Allegheny there are only occasional narrow terrace remnants on the west side of the valley.

On the east side the gravel filling makes a singular detour southward from Morningside to East Liberty, and thence eastward past Allegheny cemetery to the river, encircling high uplands. At East Liberty it occupies the northern end of an abandoned oxbow of the Monongahela, known as the East Liberty Valley. The gravel is well displayed on the west side of Negley Run, and thence westward to the Allegheny cemetery, up to an altitude 260 to 270 feet above the river, and about 60 feet above the old oxbow channel of the Monongahela. It is mainly a very fine gravel with a large admixture of sand. West from the cemetery an old gravel is found down to a level only about 100 feet above the river. The exposures show coarse blocks for a few feet above the rock floor, such as appear along a river bed, and above this is gravel of medium coarseness. The old gradation plain stands nearly 200 feet above the river, or about 100 feet above the lower limit of the old gravel. Possibly 100 feet of trenching preceded the deposition of the gravel, but here, as at Arnold, the relation of the gravel deposition to valley trenching remains uncertain.

From near Allegheny cemetery the gravel passes to the west side of the river at "Mount Troy" in the east part of Allegheny, where a narrow remnant of the old gradation plain is preserved. It also covered "Monument Hill" in Allegheny, an island-like remnant of the gradation plain, but nearly all the gravel has now been removed from this hill.

In closing this discussion of the Allegheny Valley a few paragraphs are selected from Jillson's paper which contain levels taken in the vicinity of Pittsburg.[1] The altitudes were in all cases obtained by Locke hand level from the nearest railway track. The base is the city datum, 698.43 feet above mean tide at Sandy Hook.

In describing the terraces belonging to the Pittsburg group we will begin with "Monument Hill." This hill stands on the north side of the Allegheny River, and is a typical "hog's back," 1,500 feet long and exactly 200 feet high. On its top is a thin layer of gravel, in which several pieces of granite have been found, one 2 inches in diameter. "Mount Troy" rises abruptly from the north bank of the Allegheny. It is 209 feet in height, a mile and a half in length, and throughout is as level as a floor. Its top is covered with foreign gravel, and at the west end the water basin was excavated from a mass of coarse gravel and cobblestones. In the Allegheny cemetery three terraces can still be seen, though much changed by necessary improvements. Entering the cemetery from Butler street by the old gate and passing up the stone steps to the right, we find a terrace 120 feet above our base line. This terrace can be easily followed along the east side of Butler street through the United States Arsenal grounds to Penn avenue. At the corner of Davison and Forty-sixth streets its height is 134 feet; in the arsenal grounds it is 125 feet, and near the junction of Forty-second and Sherman streets, 158 feet.

In the upper part of Allegheny cemetery is an immense mass of sand and gravel, the highest point of which, near the monument erected to the memory of those killed by the arsenal explosion in 1862, is 250 feet. The character of this deposit is well shown just back of the receiving vault, where the sand has been removed, exposing a perpendicular section 25 or 30 feet in height and some 75 feet in length. The base of this section is 213 feet above our base line. No outcrop of rock is seen in the immediate vicinity, but not a great distance off a layer of shale was found in situ 22 feet below it. Whether this shale is at the top of the rocky bed I have at present no method of determining. At Geneva and Main streets this shelf is 200 feet in height; at Liberty avenue and Fortieth streets, 206 feet. The bed of sand and gravel extends from the cemetery across Penn avenue into the East Liberty Valley at Bloomfield, and, like other beds found at this height, consists of stratified sand, gravel, cobblestones, bowlders, and angular fragments, many pieces being of material not properly belonging to the rocks of this vicinity. The top of this bed at Pearl street, where it crosses Penn avenue, is 259 feet; at Forty-fifth street, 256 feet; at Rebecca street, 274 feet. At Thirty-third street, just above the

[1] Op. cit., pp. 6–10.

Lawrenceville station, on the Pennsylvania Railroad, is a well-developed terrace which extends to the West Penn Medical College. At Brereton and Dickson streets its height is 195 feet; at Thirty-third street it is some 10 feet higher. The Bedford Avenue water basin, near the Union railroad station, was excavated in part from a terrace which at that point is 178 feet in height. Several houses which were built on the original terrace before the avenue was graded still remain. This terrace, extending from the water basin around the hill to Crawford street, though now covered with houses, can be traced without difficulty by an examination of dooryards, wells, and other excavations. On Fulton street, at the foot of Center avenue, its height is now 194 feet. * * *

The great canyon of the Ohio has formed an amphitheater at Pittsburg nearly 3 miles long and more than 1 mile wide. This amphitheater is completely surrounded by high cliffs, except the narrow gorge on the east through which the Allegheny enters, and the one on the west through which the Ohio departs. On the walls of this amphitheater are two distinct horizontal lines; the lower one, as we have seen, appears in many places from 140 to 150 feet above the river, while the upper is a well-marked shelf or terrace 200 feet above low-water mark in the Allegheny. Directly connected with the 200-foot level is the ancient river bed of the Monongahela, which at one time ran through the East Liberty Valley. It entered the valley a few miles below Braddock's, passed a little to the west of Swissvale and Wilkinsburg railroad stations, through Brushton, Homewood, East Liberty, and Shadyside to Herron's Hill. This hill presented an insurmountable barrier to its further progress in this direction, and here it divided, the left branch forming the plain on which so many beautiful houses in Bellefield and Oakland have been built; the other passed to the right of the hill, joining the Allegheny. Through its whole course we find well-marked evidence of river action—huge bowlders, smoothed and rounded by being rolled over and over in the bed of the river; great banks of sand and gravel distinctly stratified; large heaps of cobblestones and other characteristic marks. The position of the bed-rock is determined, not only by outcrops at the beginning and end of the valley, but also by the sides of the railroad which passes through it, and by numerous wells and other excavations. Ditches dug for sewers, water, and gas pipes show the greatest depth of the deposit to be from 20 to 25 feet near the middle of the valley, gradually growing less in depth towards the sides. Another evidence of river action is shown by a well-defined "second bank," which runs along the southern side a distance of more than 2 miles. On this second bank is now located Fifth and Penn avenues from Shadyside nearly to Wilkinsburg. From the top of this bank to the Pennsylvania railroad track is an abrupt descent of many feet. Before Penn avenue was graded a person going from East Liberty to Wilkinsburg soon made a steep ascent at Point Breeze hotel, reaching the top of this bank. Passing along it nearly to Wilkinsburg, at the old "yellow tavern" on the left, he plunged into the old river bed, crossing which he reached his destination. At Homewood and Penn avenues this second bank is now 79 feet above the ancient river bed; at Fifth and Shady avenues, 71 feet; and at Amberson and Fifth avenues, 54 feet.

Before leaving East Liberty Valley let me call your attention to a point of considerable importance. The great deposit of gravel containing foreign material, in Allegheny Cemetery, extends into the East Liberty Valley, and was deposited on the

detritus of our ancient river. * * * When the Allegheny River ran 300 feet above its present level it overflowed its banks at this point, and deposited its detritus in the cemetery and in this valley. Between Negley and Highland avenues is another deposit of a similar character, showing a similar overflow when the Allegheny River was 300 feet higher than at present. This "overflow" deposit consists of 15 feet of gravel above and at least 22 feet of fine sand below; the gravel contains much foreign matter, some large pebbles and many angular stones, sometimes a foot in diameter. About 8 feet from the top was found a rectangular stone which measured 33 inches by 36, by 13, with sharp edges and angles; it was a conglomerate, distinctly stratified, and composed of very small grains of well-rounded white quartz. The nearest bed-rock was found in a ravine 27 feet below the base of the gravel.

UPPER OHIO VALLEY.

The terraces on the Upper Ohio being a direct continuation of those on the Allegheny, a similar series of deposits is presented. The first prominent remnant of the high-level glacial gravel is found in the western part of Allegheny, and extends from that place down the valley past Bellevue, a distance of nearly 5 miles. This was recognized as a glacial terrace by White, in 1876.[1] The altitude is shown by a topographic map of Allegheny to reach in places 975 feet above tide, and the general level of the surface is above 950 feet. The width averages about a half mile. Several gravel pits have been opened. One on Woodland avenue, described by Jillson, "consists of 3 or 4 feet of clay and loam resting on 15 to 18 feet of gravel, and this on sand which has been excavated more than 15 feet." In the gravel was a granite pebble 5 by 6 inches in diameter, as well as several smaller pebbles of Canadian rocks. An exposure noted by the writer near California avenue has the following beds:

Section of gravel pit on high terrace in Allegheny.

	Feet.
1. Sandy loam	4–8
2. Fine gravel, with much sand intermixed	3–6
3. Sand, cross-bedded	4–5
4. Gravel, like No. 2	6–7
5. Sandy and gravelly material exposed	5–6

The gravel extends down to a nearly level shelf of rock, standing 890 to 900 feet above tide, or 75 to 85 feet below the highest parts of the terrace. A depth of 75 to 85 feet apparently holds all along the terrace. Wells in Bellevue 60 feet in depth have not reached the bottom of the gravel.

A few miles farther down the Ohio, near Sewickley, a narrow terrace, standing about 200 feet above the river, was found by Jillson to carry

[1] Second Geol. Survey Pennsylvania, Rept. Q, pp. 12, 175.

"many bowlders, cobblestones, and a little metamorphic gravel." One granite bowlder 2 feet long and 1 foot in diameter was noted.

Wright has found on a terrace back of Middletown, on the south side of the Ohio 12 miles below Pittsburg, rolled stones and an occasional pebble of granite at 250 to 280 feet above the river. For several miles below these points terrace remnants are very small.

Near the mouth of the Beaver extensive terrace remnants appear. One back of Phillipsburg, south of the Ohio River, carries gravel at an altitude about 310 feet above the river, or 975 feet above tide, and one back of Beaver, on the north side, has a gravel deposit at equally high altitude. This was well exposed by trenches for waterworks at the time the writer last visited that locality (in 1898), and several granite rocks, ranging in size from nearly a foot in diameter down to small pebbles, were found in the material thrown from the trenches. The depth of the gravel is about 15 feet, and it is capped by a reddish, sandy clay 8 or 10 feet in depth. These terrace remnants at Phillipsburg and Beaver apparently stand at about the original level of the gravel filling. There is another terrace in that vicinity, 75 to 100 feet lower, which carries an old glacial gravel, but it was probably cut down from the level of the high terrace. This is described by White as the "Fourth terrace," and is well displayed at Rochester and New Brighton.

Just above Industry, on the north side of the Ohio, is a terrace or rock shelf, standing about 275 feet above the river, on which a few waterworn pebbles were found, including a quartzite 9 or 10 inches in diameter, and a gneiss about 3 inches.

From Industry, Pa., down to East Liverpool, Ohio, there are only occasional small remnants of the highest terrace, and none of these were closely examined. At East Liverpool the reservoir for waterworks stands on a terrace about 300 feet above river level. On this terrace there is a gravel deposit of considerable depth. Another terrace, which is also capped by old gravel, occurs about 200 feet above the river, but this apparently was cut down from the level of the high terrace. There is reported to be an extensive remnant of the 300-foot terrace on the south side just above East Liverpool, but it was not examined by the writer. A small remnant also appears on the south side below East Liverpool. Below that point the old terrace is well displayed on the north side back of Wellsville, Ohio.

The next terrace remnant examined is found on the West Virginia side

north of Tomlinson Run. It stands about 300 feet above the river and occupies an area of perhaps one-fourth of a square mile. On its surface only a few waterworn pebbles were found, there being no continuous bed of gravel.

South of Tomlinson Run there are two terraces; the upper, a narrow one, stands about 300 feet above the river and carries only scattering pebbles; the lower, a broad shelf, stands about 200 feet above the river and carries a deposit of gravel several feet in depth. In a gully in this gravel a large number of clam shells were found which seem to have been embedded with the gravel. As the gravel has probably been derived from higher rock shelves and redeposited during the process of excavation, these shells may be considerably younger than the old drift. As indicated on page 94, the valley may not have been opened to the level of this lower shelf until after the deposition of the gravel.

At a cemetery in a recess of the valley back of Toronto, Ohio, a bed of gravel was found at an altitude about 320 feet above the river, or 950 feet above tide, which contains occasional Canadian rocks. In a search of half an hour 8 pebbles of granite and quartzite were found, which represent all that occur in a collection of perhaps 10,000 pebbles. They range in size from one-half inch up to 3 inches in diameter. The deposit has a depth of 10 to 12 feet. A shelf of similar altitude appears opposite Toronto, but it carries only scattering pebbles.

Below Toronto scattering pebbles have been found on rock shelves at numerous points at levels 200 to 300 feet or more above the stream, but no bed of glacial gravel has been observed. On some of the shelves that stand 200 to 250 feet above the river appear occasional Canadian rocks, which are thought to have been lodged on these shelves during the excavation that followed the gravel deposition. The features of the Ohio Valley below the point where well-defined beds of glacial gravel occur are discussed in Chapter III (see pp. 91–93, 108–109). We may, therefore, pass to the consideration of glacial outwash in the Beaver Valley.

BEAVER VALLEY.

Only the lower 10 miles of the Beaver Valley lies outside the limits of the Wisconsin drift, the border of that drift being near Homewood. From the Wisconsin drift border southward to Beaver Falls there is a broad rock shelf standing about 875 to 900 feet above tide, or 210 to 235

feet above the mouth of the river. For a couple of miles below the Wisconsin border the shelf is nearly bare, but farther south it carries a gravel deposit 25 to 30 feet in depth. It is probable that the gravel has been removed by stream action from the bare part, for that stands below the level of the gravel surface to the south. There has probably also been considerable erosion of gravel all along the valley, for the surface of the gravel is 50 feet or more below the level of the terraces on the Ohio at Beaver and Phillipsburg.

The gravel is capped by a silt of pale color, 4 or 5 feet in depth, which may prove to be the equivalent of the Iowan loess. Its color is strikingly in contrast with that of the gravel below it. The gravel is weather stained at top and seems to be much older than the silt.

As a rule the gravel is poorly assorted and contains much sand, and in places has a clayey matrix. The largest Canadian rocks noted are nearly a foot in diameter. They are deeply weathered, the red granites being usually very rotten. A few striated stones were found in the north part of Beaver Falls, and these have been weathered deeply since the striation occurred. The proportion of Canadian rocks here, as on the Allegheny, is much smaller in this gravel than in gravel of Wisconsin age that lies in the valley below the level of this rock shelf.

Below Beaver Falls the rock shelf is less conspicuous than above that city, though a broad remnant appears on the east side in New Brighton. At this place a clayey deposit appears on the rock shelf, in which stones of various sizes are embedded.

It being uncertain whether the old drift is exposed on the uplands bordering the Beaver Valley outside the limits of the Wisconsin, the relations of the terrace to the drift can not be clearly shown. As yet it is not known whether the border of the old drift lies some distance back beneath the Wisconsin or is practically identical with it in position. There is, however, no question that this gravel, like the similar gravel on the Lower Allegheny and Ohio, has been derived from the old drift and was deposited long before the Wisconsin stage of glaciation.

The Little Beaver Valley has not been examined by the writer outside the limits of the Wisconsin drift, and nothing has been learned concerning the character of the outwash found along it.

CHAPTER VI.

THE ILLINOIAN DRIFT SHEET.

SECTION I. FEATURES NEAR THE DRIFT BORDER.

GENERAL STATEMENT.

The drift sheet here described appears to be the continuation of the Illinoian sheet so widely displayed in Illinois and western Indiana. It connects directly with that sheet at the reentrant angle in the glacial boundary in south central Indiana. From this reentrant angle eastward across southeastern Indiana, northern Kentucky, and southwestern Ohio its general aspect and relations are similar to those of the Illinoian sheet farther west, and it extends to the limits of glaciation. If the Kansan or earlier sheets of drift are present their borders probably lie within the limits of this Illinoian sheet or are so meagerly represented at the edge that they have been unrecognized.

As already indicated, the Illinoian drift has been identified no farther east than western Holmes County in north-central Ohio, at which point its border passes northward beneath the border of the Wisconsin drift sheet.

In eastern Pennsylvania and New Jersey a sheet of old drift extends beyond the limits of the Wisconsin, descriptions of which have already been given by Salisbury and others.[1] It is barely possible that this sheet is of

[1] R. D. Salisbury: Preliminary paper on drift or Pleistocene formations of New Jersey: Rept. Geol. Survey New Jersey, 1891, pp. 102–103. Surface Geology of New Jersey: Rept. Geol. Survey New Jersey, 1892, pp. 151–166. Certain extramorainic drift phenomena of New Jersey: Bull. Geol. Soc. America, Vol. III, 1892, pp. 172–182. The older drift in the Delaware Valley: Am. Geologist, Vol. XI, 1893, pp. 360–362. Surface geology; extramorainic drift: Rept. Geol. Survey New Jersey, 1893, pp. 73–123.

E. H. Williams, jr.: Glaciation in Pennsylvania: Science, Vol. XXI, 1893, p. 343. South Mountain glaciation: Bulll. Geol. Soc. America, Vol. V, 1894, pp. 13–15. Extramorainic drift between the Delaware and Schuylkill: Bull. Geol. Soc. America, Vol. V, 1894, pp. 281–296. Age of the extramorainic fringe in eastern Pennsylvania: Am. Jour. Sci., 3d series, Vol. XLVII, 1893, pp. 34–37. Notes on the southern ice limit in eastern Pennsylvania: Am. Jour. Sci., 3d series, Vol. XLIX, 1894, pp. 174–185.

A. A. Wright: Extramorainic drift in New Jersey: Am. Geologist, Vol. X, 1892, pp. 207–216. Older drift in the Delaware Valley: Am. Geologist, Vol. XI, 1893, pp. 184–186. Limits of the glaciated area in New Jersey: Bull. Geol. Soc. America, Vol. V, 1894, pp. 7–13.

Illinoian age, though from its general characteristics it appears to be of similar age to the old drift of northwestern Pennsylvania, i. e., Kansan or pre-Kansan.

The extent of the Illinoian drift having been set forth in some detail in the discussion of the drift border, we may pass at once to the discussion of its features.

TOPOGRAPHIC EXPRESSION OF THE DRIFT BORDER.

The border of the Illinoian drift shows definite ridges or knolls at only a few places, as specified below. The drift has, however, along much of its border, sufficient thickness to produce a marked effect on the topography. The valleys and ravines lying just within its border have received much more drift than the uplands or divides between the streams. As a result there is a marked reduction in the depth of valleys in the drift-covered region compared with similar valleys in neighboring driftless tracts. In places where a very thin coating or only scattering bowlders appear on the dividing ridges, the valleys usually carry 50 to 100 feet or more of drift. These deposits in the valleys often terminate very abruptly at the drift border, both on drainage lines which were blocked by the ice in their lower courses and on lines which were open during the glacial deposition. The abrupt termination affords strong evidence that the ice sheet extended to the extreme limits of the drift. Lakes were no doubt formed in valleys that were obstructed by the ice sheet, but there appears to have been comparatively little transportation of material from the ice margin into the lakes. The rate of removal of material in unobstructed valleys was also somewhat less rapid than the rate of deposition by the ice sheet. The variations in the topographic expression may perhaps be best discussed by following the border from the reentrant in Monroe County, Ind., eastward to the point of disappearance beneath the Wisconsin drift in Holmes County, Ohio.

On the elevated upland north of Beanblossom Creek, in northeastern Monroe County, Ind., there are many bowlders but only occasional thin deposits of till; but on passing down into Beanblossom Valley, at Needmore, the drift border changes abruptly to a bulky ridge which rises like a dam 60 to 75 feet above the valley bottom to the west, and blocks the valley for a space of fully a mile. Its surface is indented by shallow basins

and carries also a few low swells. There was probably considerable obstruction, if not a complete damming, of the lower course of Beanblossom Creek by the portion of the ice sheet immediately west of the reentrant angle. Such an obstruction is suggested not only by the fact that the lower course of the creek enters the drift-covered region but also by the features in the part of the valley just below the drift ridge at Needmore. Only an occasional pebble appears below the ridge to testify to transportation of glacial material down the valley.

South from Beanblossom Creek considerable till is banked against the slope, but the dividing ridge carries only bowlders and occasional thin deposits of till. The bowlders, as noted above, have apparently been rolled down ravines south of the divide to some distance beyond the ice margin.

In Salt Creek Valley the drift border connects with a glacial terrace that leads down the valley beyond the limits of Brown County. Where uneroded this terrace stands fully 50 feet above the present stream. The valley of Salt Creek seems to have been the main line of discharge for glacial waters in the elevated region. The drift deposits at the place where the ice margin crossed the valley are not so conspicuous as on Beanblossom Creek, probably because so large an amount was carried down Salt Creek Valley during their deposition.

On the elevated uplands in eastern Brown County the drift is in places 40 feet thick, but it is usually a thin deposit, scarcely sufficient to form a continuous drift sheet. There appears to have been some outwash into Middle Salt Creek, for gold, supposed to be of glacial derivation, is reported to occur in the alluvium at Elkinsville,[1] but it was a less important line of discharge than the North or main Salt Creek Valley.

On the low plain in Jackson County a prominent drift ridge, known as "Chestnut Ridge," stands near the glacial boundary. It is not at the extreme limits of the drift, there being a plain west of it a few miles in width which is underlain by clay and sand carrying glacial pebbles. It should, however, be considered in connection with the drift border, since it is not unlikely that the ice sheet formed this ridge while it was still occupying neighboring parts of the drift border.

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[1] Rept. Geol. Survey Indiana, 1874, p. 107.

This ridge was brought to notice by E. T. Cox, of the Indiana survey, in his report on Jackson County,[1] and its position was indicated on the county map accompanying that report. With the ridge Cox included some sand hills southeast of Seymour, which are evidently of different origin from the ridge. The northern terminus of the ridge is at the south bank of Mud Creek, 3 miles due south of Seymour. From this point it leads slightly west of south through Dudleytown toward Mount Sidney, a distance of about 8 miles, its southern terminus being 3 miles north of Mount Sidney. The village of Dudleytown stands about the middle of the ridge. The width nowhere exceeds 1 mile, and is usually scarcely a half mile. The height ranges from 50 to 170 feet above the bordering plain. Being so narrow its highest portions constitute a prominent feature in the landscape, rivaling the hills that have a rock nucleus. That this ridge has not a nucleus of rock is shown by a series of wells whose sections are given below. From these sections it appears that the drift extends in places to a level fully 50 feet below the base of the ridge, and contains till as well as assorted material. The crest of the ridge is very uneven, dropping down in places to within 50 feet of the bordering plain, and then rising to 100 feet, and in one place to 170 feet by surveyor's level, above the plain. There is little question that the ridge should be classed as a moraine. It was so considered by Cox at a date when but a few moraines had been recognized in North America. While several moraines of Wisconsin age, in Indiana, exceed it in bulk, none of them forms a more prominent landscape feature.

From the terminus of Chestnut Ridge southward to the Ohio River the drift on the lowlands is usually a continuous sheet which in places reaches a depth of 40 feet or more, but on the uplands along the extreme border there are in places only scattering bowlders to indicate the glaciation. The surface of the drift on the lowlands is very flat, with scarcely a trace of knolls or ridges.

Along the Ohio Valley the character of the drift border is extremely variable. In places only bowlders and thin patches of drift are present, while in other places there are knolls and ridges of considerable size. Among the common features in northern tributaries of the Ohio, a short distance inside the glacial boundary, are clusters of large knolls standing near the base of the bluffs, or plastered on the slopes. Some clusters con-

[1] Rept. Geol. Survey Indiana, 1874, pp. 41–75.

tain a central knoll rising to a height of 75 to 100 feet, around which are smaller ones; in other cases there are chains of knolls, and occasionally an isolated knoll appears. The Ohio Valley itself carries several clusters of knolls between Vevay, Ind., and the mouth of the Great Miami at the Ohio-Indiana State line. More commonly the drift accumulations in the Ohio Valley have a level top like a terrace and stand 150 to 200 feet above the river. It should not be inferred, however, that this level-topped drift filling represents a fluvial terrace, for it appears to be the product of the ice sheet, just as in the case of level-topped drift surfaces on the uplands. It consists largely of till or of poorly assorted material and is very unequal in amount in different parts of the valley. Occasionally it fills the valley to a height of 150 to 200 feet above low water, while in other places there appears to have been much less filling.

Near Carrollton, Ky., a definite drift ridge appears between the Ohio and Kentucky rivers, apparently at the extreme limits of glaciation, which, not only because of its position but also because of its contours, may be classed as a moraine. The highest points stand nearly 200 feet above the Ohio River, but the low parts of the crest are scarcely 125 feet above that stream. On either side of it are terraces of the Ohio and Kentucky rivers, standing about 90 feet above the streams. The ridge is scarcely a half mile in width and consequently rises sharply above the terraces. It leads directly east across a gap in the rock ridge between the two rivers. This drift ridge consists largely of till and carries many striated stones. The question whether it may be a reduction by erosion from a drift filling with level top, such as appears at intervals farther up the Ohio, was considered by the writer while on the ground, but it seemed that the contours are better explained as the product of drift deposition than of drainage erosion. From the eastern end of this drift ridge the drift border rises to an upland tract with an altitude more than 300 feet above the Ohio. On this upland, which is greatly dissected by valleys and ravines, the drift forms a conspicuous deposit along the ravines that discharge northward to the Ohio, but there is a very meager deposit on the ravines that lead southward to Eagle Creek, a feature which is to be expected where the glacial boundary lies near the divide.

For a few miles up the river from Vevay, level-topped remnants of a drift filling appear at an altitude about 150 feet above the river. They are

most conspicuous where tributaries enter. In the valleys of these tributaries there are clusters of knolls, as indicated above. Just above the bend near Patriot, Ind., along the west bluff of the Ohio, are clusters of knolls which are composed of clay or poorly assorted material similar to that in the level-topped drift tracts. The highest stand about 150 feet above the Ohio, or at about the level of the plane-surfaced valley filling. Their form seems to favor the view that they are due to irregularity of drift deposition rather than to the erosion of a plane-surfaced drift deposit. Similar knolls are found on the Kentucky side below Rising Sun, Ind., and in places along the border of the Indiana bluff above Rising Sun. They rise about 50 feet above the level of gravel terraces of Wisconsin age, or 150 feet above the river.

Near Bellevue, Ky., the drift is aggregated in knolls up to a height of 250 to 300 feet above the river, but the drift deposits on the elevated uplands between Bellevue and Burlington, Ky., have a plane surface. The drift is decidedly greater in amount on the southern branches of Gunpowder Creek than on the uplands farther north near the bluff of the Ohio. Near Richmond, Ky., it is a conspicuous deposit within a mile of the limits of glaciation on a branch of Gunpowder Creek that discharges northward, but is very meager on Mud Lick Creek drainage, whose discharge is southward. The presence of drift in the Mud Lick drainage basin shows, however, that the ice sheet extended beyond the Gunpowder–Mud Lick divide.

Above Cincinnati, for the 50 miles in which the glacial boundary lies near the Ohio River, there are numerous level-topped remnants of a drift filling that stand about 150 to 175 feet above the river. It is probable that much of that portion of the Ohio Valley received a drift filling up to these heights. Just above Higginsport, Ohio, on the east side of the mouth of White Oak Creek, there is a glacial conglomerate extending up to a height of 235 feet (aneroid) above the Ohio, forming a narrow bench on the border of the valley. A drift deposit appears on the Kentucky side opposite Higginsport which also carries conglomerate masses, but its upper part consists of till. It rises only to a height of 175 feet above the river, its altitude being nearly in harmony with the general drift filling below that point. It is near the Higginsport conglomerate that the glacial boundary swings away from the Ohio Valley toward the northeast.

The writer has not examined the portion of the border lying between

the Ohio River and the head of Brush Creek, but from Wright's description it appears to be plane surfaced and rather attenuated.[1]

From the head of Brush Creek, in Pike County, Ohio, eastward to the Scioto, the Wisconsin and Illinoian drift borders are nearly coincident. The Illinoian drift, however, appears along the south side of Paint Creek Valley outside the limits of the Wisconsin. It shows a marked tendency to aggregate in knolls, there being several prominent clusters between Bainbridge and Chillicothe. These knolls, like those on tributaries of the Ohio in southeastern Indiana, are banked against the base or stand on the slope of the bluff. They rise abruptly in several instances to a height of fully 100 feet above the low parts of the creek valley. Around and back of these knolls there are deposits of drift, but the high uplands south of Paint Creek appear to be unglaciated. On the east border of the Scioto Valley, opposite Chillicothe, a high glacial terrace, standing about 60 feet above the Wisconsin terraces, or 120 feet above the Scioto River, apparently connects with the Illinoian sheet of drift. Near the point of connection it carries shallow basins similar to those so often found on outwash aprons bordering morainic systems of Wisconsin age. The drift immediately north of the head of this terrace is of gravelly constitution, and it grades into the terrace in the manner so common in moraines of Wisconsin age. However, no knolls or ridges of morainic type were found in this portion of the Illinoian drift border.

On the hilly country between the Scioto Valley and Salt Creek Valley the drift border on the high ridges is attenuated, consisting only of bowlders and thin patches of till. In the ravines, however, deposits of considerable depth appear.

In Salt Creek Valley, below Adelphi, for a distance of 5 miles there are heavy accumulations of drift, with nearly plane surfaces, which rise about 150 feet above the creek level and give the appearance of terraces on the valley borders. These deposits terminate abruptly at the drift border, there being a low plain extending from bluff to bluff along the portion of Salt Creek east of the drift border. It is probable that a lake occupied this part of the creek valley during part, if not all, of the Illinoian stage of glaciation, for the preglacial course of the stream, as noted on page 178, was

[1] Glacial Boundary in Ohio, pp. 68–72.

westward to the Scioto Basin, and it became necessary to open a new line of drainage toward the south.

In much of the interval between Salt Creek and Hocking River, as indicated above, the Wisconsin drift apparently extends to the limits of glaciation. The Illinoian drift border, however, probably lies only a short distance back beneath the Wisconsin. Possibly an attenuated margin of Illinoian drift may be found outside the Wisconsin in a part of this interval, but from the examination already made it is evident that no conspicuous sheet of Illinoian drift is exposed. In the Hocking Valley and its tributaries, and also in an abandoned valley east of Lancaster, large knolls of Illinoian drift, similar to those found in the Ohio River and Paint Creek valleys, appear, sometimes in clusters and sometimes isolated. In some cases they are 50 to 75 feet in height. Aside from these knolls, which seem confined chiefly to the valleys, the drift surface in that part of the border is plane. The filling of ravines is sufficient there, and also in the part of the drift border farther north, to cause a striking contrast between the drift-covered and the driftless tracts. Very few knolls appear along the portion of the border between the Hocking and Licking rivers.

In the Licking Valley east of Hanover is an accumulation of sand, gravel, and silt at the drift border, presenting the form of a great dam across the valley. It stands more than 100 feet higher than portions of the valley above and below it, and occupies the whole width of the valley for a space of about 2 miles. The valley being about a mile wide, the area occupied is not less than 2 square miles. The top is nearly plane, but descends gradually eastward; the west, or inner face, is very abrupt. The deposit appears to be an outwash from the ice sheet into a body of water held in the valley to the east. Much of the material is a fine silt, and there is none coarser than fine gravel. The surface capping is coarser than the deeper part. West from this great dam there are low knolls in the bottoms and on the slopes of the valley which were probably formed beneath the ice margin. They are much less conspicuous than the dam. Prominent drift knolls occur in the valley of Wilkins Run a few miles northwest of Hanover, as noted by Wright,[1] which appear to be of Illinoian age. They rise 75 to 90 feet above the creek level, and are classed by Wright as "extramarginal kames." They apparently lie outside the

[1] Glacial Boundary in Ohio, p. 52.

Wisconsin drift border, but they are several miles inside the Illinoian border, and are therefore extramarginal only to the Wisconsin drift.

From the Licking Valley northward to the point where the Illinoian drift border passes under the Wisconsin the drift is generally thin on uplands, but has considerable depth in valleys. Knolls such as occur in Wilkins Run Valley are very rarely seen in this part of the drift border. A few, however, appear in the valley of Mohican Creek, and others may occur which have escaped notice.

STRUCTURE OF THE DRIFT BORDER.

The drift border generally consists of a sheet of moderately stony till similar to the widespread sheet of which it is the terminus. Portions of it are thickly set with large bowlders, but more commonly it contains only small stones a foot or less in diameter. On the borders of valleys that afforded a good line of discharge for glacial waters the till has lost much of the fine material, and consists of a more or less thoroughly assorted gravelly deposit. It is seldom, however, distinctly bedded.

The large bowlders are mostly of granite rocks, but quartzites and greenstones are not rare, while occasional red jasper conglomerates have been noted. There are also a limited number of other crystalline rocks of Canadian derivation. South from the Ohio bowlders exceeding 1 foot in diameter are rare; there are, however, a few that reach 3 or 4 feet in diameter.

In a few places extensive masses of glacial conglomerate have been formed, of which perhaps "Split Rock," near Aurora, Ind., is the most widely known. These conglomerate masses are especially conspicuous in the Ohio Valley, not only at Split Rock, but at points below, near Vevay, Ind., and Carrollton, Ky., and at points above, near Augusta, Ky., and Higginsport, Ohio. They occur at various levels, from about 50 feet below the Ohio River up to fully 300 feet above the stream. The matrix of the conglomerates is usually a calcareous material much like the fine parts of the till. Indeed, the conglomerates seem to be an exceptionally stony till rather than a gravel. The coarse fragments are mainly limestone slabs, though occasional Canadian rocks occur. The thickness of these conglomerate masses ranges from a few inches up to 100 feet or more. In places they are like large concretions in the midst of an uncemented till; in other places they

form sheets extending horizontally for a mile or more. "Split Rock" is a detached mass of such a conglomerate lying in the river on the Kentucky side. The conglomerate from which it is broken extends up to a height of nearly 100 feet above the river and for a distance of one-eighth mile or more along the bank. It extends for more than a mile along the valley, lying mainly below the mouth of Wolper Creek. Back of this, at a height of about 300 feet above the river, is another conglomerate mass, known as the "Middle Creek conglomerate," which was discussed some years since by Sutton.[1] From the wide difference of level at which these conglomerates occur Sutton drew the inference that they are widely different in age, it being assumed that they are terrace remnants. In the writer's opinion, as just indicated, the conglomerates are to be classed as exceptionally stony till rather than the deposit of a stream, and the wide difference in altitude may signify nothing as to time relations. Indeed, the writer was unable to discover any evidence that the two conglomerates differ greatly in age. An uncemented stony deposit above the level of the upper conglomerate is discussed below.

A sheet of silt or white clay covers the Illinoian drift in this region as well as in the region to the west occupied by the Illinois glacial lobe, which appears to be a continuation or extension of the loess of the central part of the Mississippi Basin. The white clay is but 3 to 6 feet thick on the flat parts of this region, and is usually largely removed from valley slopes. The drift knolls above noted are covered by it unless their slopes are very abrupt. It conceals the till and bowlders to a great degree on the uplands, leaving only the eroded valley slopes to afford natural exposures. The amount of white clay is not sufficient to produce a notable valley filling. It thus differs from the till which, as stated above, has filled valleys to a perceptible degree all along the drift border. The distribution, structure, and relationships of the white clay are taken up in some detail farther on. The structure of the drift border may generally be easily determined from natural exposures, and such exposures have furnished data for the statements just made; but in valleys, and also on Chestnut Ridge, wells have been of service in revealing the drift structure. A few records are accordingly given.

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[1] Glacial or ice deposits in Boone County, Ky., of two distinct and widely distant periods, by George Sutton: Proc. Am. Assoc. Adv. Sci., Vol. XXV, 1876, pp. 225–231; also Tenth Ann. Rept. Geol. Survey Indiana, 1878, pp. 108–113.

In Beanblossom Valley near Needmore, Ind., the wells reach a depth of about 50 feet, and the material penetrated is said to be in the main similar to that at the surface, a very stony, almost gravelly, till of brown color.

In East White Valley wells are seldom 50 feet in depth, and are largely through sand and fine gravel. This is probably referable in the main to the Wisconsin stage of glaciation. On the lowlands west of the valley the wells ordinarily penetrate 8 to 10 feet of pebbleless clay, beneath which they enter till. Beds of gravel associated with the till furnish a supply of water.

At Seymour, Ind., on a low sandy plain east of White River Valley, the wells are driven through sand and sandy clay to a depth of 50 feet or more without encountering a stony clay. The deposits may be alluvial rather than glacial. A gas-well boring penetrated 75 feet of Pleistocene deposits, as follows:

Section of Pleistocene deposits in a gas boring at Seymour, Ind.

	Feet.
1. Coarse sand	12
2. Very fine sand or silt, almost a clay	43
3. Black muck, probably an old flood plain of the river	10
4. Coarse sand with a large amount of water	5
5. Blue clay	5
Total	75

The black muck of this section is often found in the vicinity of Seymour at a nearly uniform altitude, and seems likely to be an old flood plain over which sand and silt have been deposited, either by water or by wind. A short distance east from Seymour the rock comes up to a level as high as the well mouth.

On the plain bordering Chestnut Ridge south from Seymour, water is usually obtained at a depth of 30 feet or less, though a few wells are as deep as 40 feet. The wells are mainly through fine sand or clay, yellow at top but of blue color at a depth of 16 to 18 feet. A flowing well on this plain is reported by Cox to obtain water in a soft shale beneath alluvium and drift at a depth of 27 feet. The well is located on a branch of Pond Creek, in sec. 7, T. 4 N., R. 5 E., a few feet below the general level of the plain.

The following sections of wells were obtained on Chestnut Ridge.

The section of Harvey Morris's well. near the north end of the ridge, 89 feet in depth, is as follows:

Section of Morris well on Chestnut Ridge.

	Feet.
1. Clay, containing a few pebbles in lower part	20
2. Fine sand, becoming gravelly near the bottom	69
Total	89

Jerry Anderson's well, also near north end of ridge, 95 feet in depth, has the following section:

Section of Anderson well on Chestnut Ridge.

	Feet.
1. Clay, pebbleless at surface but quite pebbly below; blue in lower part	52
2. Gray sand, too fine to screen but yielding water	38
3. Gravel	5
Total	95

Hiram Love's well, 57 feet in depth, has the following section:

Section of Love well on Chestnut Ridge.

	Feet.
1. Surface clay and yellow till	20
2. Blue till	30
3. Gravel and sand	7
Total	57

A well at Mr. Wieneke's, on the highest point of the ridge, 77 feet in depth, penetrates the following strata:

Section of Wieneke well on Chestnut Ridge.

	Feet.
1. Sandy loam	15
2. Loose sand	18
3. Reddish gravel and sand with clay admixture, probably till	40
4. Coarse gravel	4
Total	77

A strong spring gushes out of the slope of the ridge west of Wieneke's residence at about the level of the bottom of the well and probably from the same gravel bed. At M. T. Cox's residence, on a low part of the ridge, scarcely 50 feet above the bordering plain, a well 107 feet in depth penetrates strata as follows:

Section of Cox well on Chestnut Ridge.

	Feet.
1. Till	50
2. Fine sand	25
3. Gravelly sand	32
Total	107

Wells in Dudleytown, also on a low part of the ridge, obtain an abundance of water at less than 50 feet. Henry King's well, on the slope of the ridge south of Dudleytown, perhaps 30 feet above the level of the border plain, reaches a depth of 63 feet. John W. Collins's well, near the south end of the ridge, at an altitude nearly 100 feet above the plain, obtains water at 50 feet. A log was penetrated near the bottom in a sandy blue clay.

In the vicinity of Mount Sidney, on the borders of the Muscatatuck River, wells are obtained at 40 to 45 feet in sand and gravel below till. The water bed is apparently a little higher than the level of the river.

Along the Ohio Valley several wells penetrate to a level considerably below the Ohio River before striking rock, and these probably in some instances pass through drift of Illinoian age. C. E. Siebenthal reports that at Utica, Indiana, a well standing on ground 40 to 50 feet above the Ohio River reached a depth of 120 feet before striking rock, while several wells west from Jeffersonville penetrate to a level lower than the river without striking rock. They are mainly through sand and gravel. Siebenthal holds the opinion that the Ohio may have formerly had its course through the north edge of the valley back of Jeffersonville.[1]

At Madison, Indiana, several wells have reached a depth of 120 feet without entering rock, but they are on a terrace standing about 100 feet above the river. The terrace seems to be of Wisconsin age, but there may be gravel and sand of Illinoian age under the Wisconsin gravel. The wells are reported to be entirely through sand and gravel.

At Carrollton, Ky., a boring at Jett's distillery, which stands near the mouth of Kentucky River about 60 feet above the low-water level of the river, reached a depth of 107 feet without entering rock. It terminated in a conglomerate which appears to be similar to that found in the banks of the Ohio above Carrollton, and which, like that conglomerate, is probably of Illinoian age.

Near Vevay, Ind., cemented gravel, which may be Illinoian, appears under loose gravel of Wisconsin age. The village of Vevay stands on a terrace about 80 feet above the Ohio, and wells are usually obtained at depths of 60 to 80 feet.

The Split Rock and associated conglomerates near Aurora, Ind., have

[1] Twenty-fifth Ann. Rept. Geol. Survey Indiana, 1900, pp. 359–364.

already been noted. Above the upper conglomerate there is, near the headwaters of Middle Creek, a deposit of assorted drift, which, so far as observed by the writer, is uncemented. Since this has not been mentioned by other writers a brief account of it will be given. By following the road leading south into Middle Creek Valley, past the rock spring, one finds exposed: First, the silt at the top of the bluff, which is here about 5 feet in thickness; second, a sand of gray color and free from pebbles near top, but becoming brown and pebbly below, and finally grading into a coarse gravel and cobble, the whole formation having a thickness of about 50 feet. For a vertical distance of perhaps 50 feet below the base of this deposit there are scarcely any signs of drift on the slope, there being outcropping ledges of rock. The upper conglomerate then sets in and occupies a vertical distance of about 100 feet. There are numerous large masses of detached conglomerate, and that which remains attached to the hillside is fissured deeply and presents a very uneven surface. The rock spring issues from this conglomerate.

At the base of a large mass of conglomerate near the rock spring an uncemented gravel was found whose pebbles are of medium coarseness. An examination of the pebbles indicates that not more than 1 per cent are of Canadian derivation, the remainder being mainly local limestone. No exposures of the conglomerate were found on continuing the descent from the rock spring to Middle Creek, the greater part of the slope having outcrops of limestone. The extent of the Middle Creek conglomerate is not known, but it has been observed at intervals for 3 or 4 miles northward from the rock spring. Sutton has traced it to within 2½ miles of Split Rock. He has also traced it some distance southward from Middle Creek (see paper cited above). On the farm of W. T. Ryle, about a mile north of the rock spring, there are slight exposures of what may prove to be a drift conglomerate. The outcrop consists of a mass of loosely cemented stones, some of which are angular and others well rounded. They are mainly limestone, but chert pebbles were also observed. No Canadian rocks were found in these beds, but some loose ones occur on the slope near the same horizon, which may have weathered out. Should these outcrops prove to be glacial deposits the conglomerate horizon would be of about the same altitude as the uncemented gravel near the top of the slope above the rock spring. There are on Mr. Ryle's farm, and also on farms east of the rock

spring, low knolls along the brow of the bluff, whose tops rise above the general level of the uplands. The writer was unable to ascertain whether they have a nucleus of rock or are drift knolls. The slopes of Middle Creek Valley westward from the rock spring are not smooth like those of the river bluffs, but have irregularities of outline that are due to drift deposits. These irregularities have not the sharp outline which morainic knolls commonly present, but their lack of sharpness of outline may be a result of denudation consequent upon great age. Were they of as recent age as the morainic knolls of the Wisconsin stage their outline should still be sharp. At the junction of the north bluff of Middle Creek with the east bluff of the Ohio, and at the base of the bluffs, there is a group of knolls standing 50 to 70 feet above the valley bottom, which also appear to be drift aggregations, but there are not sufficiently deep exposures to throw light upon their structure.

A gas boring at Aurora, on ground standing 45 to 50 feet above the river, reached a depth of 92 feet before entering rock. It was largely through sand and gravel. At Rising Sun, Ind., a few miles below Aurora, a well reached a level 60 feet below the river without encountering rock. Only a half mile from this well, on the Kentucky side, rock extends half way across the river at about low-water level.

At Lawrenceburg, Ind., Orton noted an outcrop of a blackened clay, apparently a soil, along the river bank, a description of which appears in the Geology of Ohio.[1] The Wisconsin gravel terrace at that point stands 80 to 85 feet above the river, and the gravel appears to be of Wisconsin age down nearly to river level, where this blackened clay outcrops. A gas boring at Lawrenceburg reached a depth of 140 feet before entering rock. The rock floor is, therefore, about 60 feet below this blackened clay and the drift between the clay and the rock floor may be Illinoian. It is reported to be gravelly. This blackened clay has been noted at a few points below Lawrenceburg at about low-water level.

In the portion of the Ohio Valley along the Ohio-Kentucky line the only well records obtained are on terraces of Wisconsin gravel, and the wells appear to terminate in that gravel near the present river level. A few in Cincinnati are deeper and reach a level 50 to 60 feet below the river before striking rock.

[1] Vol. I, pp. 426–428.

In northeastern Pike County, Ohio, in a tract known as the "Beech Flats," records of several wells were obtained within a mile or two of the limits of glaciation. These records show a heavy deposit of till. An old valley which drained that region northward to Paint Creek, as noted on page 177, has been so completely filled that the drainage is now turned southward through Brush Creek to the Ohio. The filling probably exceeds 300 feet in depth along the middle of the old valley. In a few places along Brush Creek the drift becomes stony, but well-assorted, definitely bedded gravel is rare.

The knolls along Paint Creek Valley probably contain much gravel, but it is not extensively opened.

On the high terrace in the Scioto Valley east of Chillicothe several wells have been sunk to a depth of over 100 feet, or to about low-water level of the river, without striking rock. They are mainly through uncemented sand and gravel. Occasionally thin beds of cemented gravel are passed through. A well in section 26, Springfield Township, in process of excavation at the time the writer was there, has the following section:

Section of well near head of gravel terrace in section 26, Springfield Township, Ross County, Ohio.

	Feet.
1. Surface clay and fine sand	10
2. Coarse sand and fine gravel	49
3. Cemented gravel	11
4. Fine calcareous sand with small amount of water	5
Total	75

About 2 miles west of Mooresville, on the bluff of a small tributary of the Scioto, exposures of blue till appear beneath a brown till. The blue till is less thickly set with pebbles and coarse rock material than the brown. West from this place around the base of "Mount Logan" there is a very stony, sandy till.

In the valley of Salt Creek east of Adelphi there is a calcareous blue silt up to a height about 75 feet above creek level, which apparently was deposited in a glacial lake held between the advancing ice front and the divide across which Salt Creek was turned (see p. 178). This silt is covered with about 50 feet of coarse glacial drift, much of which is very stony. Bowlders $1\frac{1}{2}$ to 2 feet in diameter are to be seen near Haynes, at the extreme limits of the glacial drift.

About 1½ miles east of Clearport, near the forks of the road, there is a good exposure of buried soil apparently of Sangamon age between the surface silt and the Illinoian drift. The soil is a rich black, but the glacial deposits below are of a pale-ash color and quite sandy. A half mile northeast from the exposure, on a tributary of Clear Creek, is a knoll of Illinoian drift about 30 feet high, which at the surface carries a slightly pebbly clay but seems to have a nucleus of gravel. The drift is very scanty from the valley in which this knoll stands eastward to the Hocking Valley at Sugar Grove.

A black, mucky soil was found between the Wisconsin and Illinoian drift in the grading of the railway leading from Lancaster to the reform school about 4 miles south of Lancaster.

In the Hocking Valley about midway between Sugar Grove and Lancaster a few drift knolls appear, one of which, near Crawfiss Institute, has been opened for gravel. The pebbles are largely of limestone and sandstone, as may be seen by the table below. In making the classification pebbles 1 to 2 inches in diameter were taken.

Classification of pebbles in a gravel knoll in the Hocking Valley below Lancaster, Ohio.

	Per cent.
Granite	2
Other pre-Cambrian crystalline rocks	9
Chert	2
Quartz	3
Clay ironstone	2
Sandstone, probably local	36
Limestone	46
Total	100

The drift in the Hocking Valley has a depth of about 200 feet at Lancaster and a still greater depth toward the head of the stream, while down the valley the thickness shows a marked decrease. The well data (as shown on p. 169) indicate that the rock floor slopes toward the Scioto Basin, or in the reverse of the present drainage. So far as could be learned from well drillers, the drift in this valley consists chiefly of sand and gravel, there being little, if any, till reported. Occasionally a "blue mud" is mentioned, but it seems to be free from bowlders or coarse rock fragments. The courthouse hill in Lancaster has a large amount of cemented gravel in its base, but there is about 40 feet of drift covering the highest part of the hill. The surface drift is till, apparently of Wisconsin age, but the underlying cemented gravel is probably Illinoian. This cemented gravel is well

exposed in a pit on the south slope of the hill. Masses of it are used for building stone walls in that vicinity.

The drift knolls east of Bern Station have in several places been opened for gravel, but they are composed in part of a stony till.

A fine exposure of till is made by a railroad cutting one-half mile east of Junction City and very near the glacial boundary. The till there has blocked the valley of East Rush Creek to a height of 100 feet above the stream and caused the stream to be deflected around a rock hill.[1]

For several miles northeast from Junction City the drift border lies along the west side of a prominent ridge, and the view from the ridge shows a great contrast between the glaciated and unglaciated territory. In the unglaciated territory there are deep, sharp valleys, while in the glaciated the valleys seem to have been filled 50 to 100 feet or more. Numerous exposures of till 10 to 15 feet thick may be seen at roadsides and along ravines in the vicinity of the drift border all through the region between the Hocking and Licking rivers. In the Licking Valley, as noted above, there is a great filling of silt with a capping of gravel and sand.

North from the Licking Valley for a few miles the drift has a very attenuated border, but near Fallsburg a sheet 10 to 20 feet or more in depth sets in at the drift border, and from there northward to the Walhonding the immediate border shows numerous exposures of till several feet in depth. North from the Walhonding the drift margin again becomes very attenuated, and continues so to the point where it passes beneath the Wisconsin drift. In places only an occasional bowlder is found to indicate the presence of the ice sheet. But within 5 miles back from the border in the valley of Mohican Creek, thick deposits of drift occur, which, as above noted, are in places aggregated in large knolls.

SECTION II. GENERAL ASPECTS OF THE ILLINOIAN DRIFT SHEET.

The preceding remarks apply mainly to the border of the Illinoian drift. It remains to discuss features back from the border.

The Illinoian drift sheet is well exposed only in the district lying outside the limits of the Wisconsin drift, for the thickness of the Wisconsin drift is usually so great as to completely conceal it. This outlying district has, in the region under discussion, an area of 6,400 square miles, more or less,

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[1] See W. G. Tight: Bull. Denison Univ., Vol. IX, 1897, p. 36.

of which about 3,200 square miles, are in southeastern Indiana, 400 square miles in Kentucky, and 2,800 square miles in Ohio. Its greatest extension beyond the limits of the Wisconsin is 60 miles, in southern Indiana. In the part which extends to the Ohio River the distance of the southern border of the Illinoian from the border of the Wisconsin ranges from 20 to 50 miles. By reference to the glacial map (Pl. II) the extent of this outlying part of the Illinoian drift may be seen. This map also serves to show the discordance between the Illinoian and Wisconsin drift borders. The Illinoian border has but one reentrant in the region under discussion, and that a very slight one, while the Wisconsin has two reentrants and three distinct lobes in the area included between the same meridians, and still other lobes farther east.

The Illinoian drift sheet presents a remarkably flat surface. There are few prominent knolls and no definite morainic ridges except those on the border above described. Much of the surface is so level as to be imperfectly drained. This is especially true in northern Clermont and Brown and adjacent parts of Warren, Clinton, and Highland counties, Ohio. A large area in southeastern Indiana is also poorly drained.

The very flat surface is found in the part of this region which is underlain by limestone. The sandstone formations in the eastern part of the region have a more uneven or diversified surface. In the limestone region there appears to have been a gently undulating upland surface similar to that of the "blue grass" region of Kentucky, where only the valleys of the main streams and the lower courses of the tributaries are deeply trenched below the uplands. The drift is sufficient usually to fill the shallow valleys, and in some cases it has so completely filled deep preglacial valleys that their courses are traced with difficulty. Among the sandstone hills it has only partly filled the valleys, though its thickness is nearly as great as in the region underlain by limestone.

In the headwater portion of the Rocky Fork drainage basin, near Hillsboro, Ohio, there are prominent drift ridges and knolls which lie near the limits of the Wisconsin drift, but which seem to be older than the Wisconsin. They are accordingly discussed in connection with the Illinoian. Near the railway there are several knolls standing either on the valley slopes or in its bottom, which range in height from about 10 feet up to fully 100 feet. With the knolls there is found a sharp ridge, 75 feet or more in

height and but 150 to 200 yards in width, which trends northwest to southeast for perhaps a half mile. Sharp knolls are found a mile or more to the southwest, near the Hillsboro and Newmarket pike, some of which reach a height of 100 feet. Similar knolls were noted near the Hillsboro and Belfast pike. They are numerous for fully 4 miles southeast from the railway, and are occasionally found farther east, near the valley of Rocky Fork. They carry a weather-stained gravel or gravelly clay at the surface, which allies them with the knolls found outside the Wisconsin, and distinguishes them from the comparatively fresh Wisconsin drift.

The Illinoian drift sheet consists very largely of a compact till. Sand or gravel beds have some development where valleys have been filled, but are very rare on the uplands. Where the till is less than 20 feet in depth its color is a yellow or brown, but if of greater thickness a blue-gray till is usually found beneath the yellow. The yellow till appears to be simply an oxidized part of a sheet which was at first blue. Its texture and the number and kind of rock constituents are so similar to those of the blue till that a separation from that till seems called for only on the ground of difference in color. Orton sought to account for the oxidized portion of the drift both in this region and in the Wisconsin drift area to the north by iceberg deposition,[1] but this interpretation was made before the limited scope of iceberg action had become known.

Both the yellow and the blue portions of the till sheet are harder than the till of Wisconsin age. This is very apparent to persons who have sunk wells in the region of overlap and to any one passing south from the Wisconsin to the Illinoian area. The indurated character of the Illinoian drift is apparently due to a partial cementation with lime, for the till contains a large amount of fine calcareous material ground from the limestone. The Illinoian till is also characterized by fissures to a much greater extent than the Wisconsin. The fissures extend down from the yellow into the blue portion and are filled with yellow or oxidized clay.

The Illinoian drift sheet appears to have been deposited in this border tract with very little abrasion of the rock surface. There are occasional exposures of residuary clay between the blue till and the rock, and in many places a very rotten rock surface appears at the base of the drift. Occasional well sections pass through a black mucky clay, probably a preglacial soil,

[1] Geology of Ohio, Vol. I, 1873, p. 430.

immediately below the blue till and a few feet above the rock. One of the most striking instances, at Mount Oreb, Ohio, and several in southeastern Indiana, are cited in the well sections which follow. Orton has reported the occurrence near Bethel, Ohio, of a soil and deposit of bog iron between the yellow and blue tills,[1] it is said to be present over an area of several square miles. Inasmuch as Orton was a careful and cautious observer, the writer does not feel free to question the evidence he cites, but it is apparently the only instance of a soil at that horizon yet reported. In this connection it may be said that several instances of the "forest bed," cited by Newberry in the Ohio reports and elsewhere, have been found to refer simply to loose fragments of wood such as are now known to occur, like bowlders, at all horizons in the till. This construction, however, may not be applicable to the case under discussion. Orton reports the following section of drift beds:

Representative sections of drift beds near Bethel, Ohio.

[Reported by Dr. E. Orton.]

	Feet.
Yellow clay, with beds of sand and gravel	20
Fine-grained clay free from grit	4
"Forest bed"	2
Bowlder clay	20–30

Upon visiting the region the writer learned through Dr. Abbott, of Bethel, that several wells in the vicinity of that village have struck logs and pieces of wood under the blue till in a gravelly bed that extends to the rock, but nothing could be learned of a buried soil in the midst of the till. Rock is struck at 40 to 50 feet.

The following notes upon the thickness and structure of the drift at certain points may be of service in illustrating or in supplementing the general statements made above:

Near the bend of Brush Creek, a short distance north of Fort Hill, in Highland County, there are deposits of till rising to a height of about 75 feet above the creek and extending to an undetermined distance beneath the creek bed. The till contains not only pebbles, but also bowlders of Canadian derivation, some of which are 2 feet or more in diameter. The great thickness of till at this point may seem remarkable, since there

[1] Op. cit., p. 443.

is scarcely any drift south and east of this creek. It is probable, however, that it is in the line of a preglacial valley.

At Mr. Sparger's, about 2 miles northeast of Fort Hill, a well 35 feet deep strikes no rock. On an adjoining farm, at Mr. Eubank's, is a well 22 feet deep which penetrates the following strata:

Section of Eubank's well near Fort Hill.

	Feet.
1. Sandy clay	10–12
2. Blue clay	6–8
2. Sand	2

At Mr. Cameron's, 1 mile south of Cynthiana, a well strikes shale at 20 feet. The drift consists of clay, yellow at top and blue near the bottom. The well is near the north border of Brush Creek Valley. Not more than 100 yards south of this well, on the bank of Brush Creek, is a gravel pit. The gravel is quite fine, few pebbles exceeding an inch in diameter. Many granite and other Archean pebbles occur. At Cynthiana, just south of the outer Wisconsin moraine, a well on Joseph Wilson's property was bored to a depth of fully 60 feet without encountering rock. It is described to be mainly in a blue clay "free from grit."

In Adams County, a short distance west of Lovett post-office, the following exposure was noted on the borders of a ravine crossed by the pike:

Road section near Lovett, Ohio.

	Feet.
1. Silt, of yellow color	2–3
2. Yellow clay containing a few Archean pebbles	4–5
3. Reddish-brown clay capping the limestone	2–3

This exposure is of especial interest, since it shows the presence of a well-defined drift sheet above the residuary clay. It also is of importance in geographic position, since it lies fully 5 miles outside the line commonly recognized through Wright's reports as the glacial boundary. In many other places in Adams and southern Highland counties a bed of reddish-brown residuary clay caps the limestone, while above it is a drift sheet.

In a trip from Sugartree Ridge to Sardinia several exposures were observed, showing the following series:

Generalized section of exposures near Sardinia, Ohio.

	Feet.
1. Clay or silt nearly free from pebbles	2–4
2. Brown till, deeply oxidized and streaked in places with brownish-black seams	3–4
3. Yellow till, usually very stony and slightly cemented; striated limestone pebbles numerous; not so highly oxidized as No. 2	6–8
4. Blue till, very stony and partially cemented; striated limestone pebbles numerous; color very deep blue, almost black in places	10–15

At a few places near Sardinia a dark band, apparently a soil, occurs between Nos. 1 and 2, but in the majority of sections observed it is not present. The deep-brown color of No. 2 marks the weathered zone and is strikingly in contrast with the pale color of Nos. 1 and 3. Its color more nearly resembles the residuary clay that rests on the subjacent limestones than that of any members of the drift series. It is fully as significant as a black soil in denoting atmospheric action. At Sardinia wells are 30 feet in depth, but none reach the rock, and rock is not exposed in valleys near there whose depth is 30 to 40 feet. Between Sardinia and Mount Oreb, near Whiteoak Creek, two exposures were observed of a soil or black band between the silt and the underlying till at a depth of 2 or 3 feet.

Near Mount Oreb station a gas well, in a depression on slightly lower ground than the station, strikes rock at 49 feet A well at J. F. Jenning's residence, on ground slightly higher than the station, penetrates 68 feet of drift and unconsolidated beds, of which the following is the section:

Section of Pleistocene beds in Jenning's well at Mount Oreb, Ohio.

	Feet.
1. Yellow clay, pebbly	14
2. Sand and gravel	6
3. Blue till	20
4. Bluck mucky clay (preglacial?)	15
5. Sand	3
6. Alternations of bluish clay and black muck extending to the limestone	10
Total	68

On the uplands in Mount Oreb, near the Christian Union Church, is a gas well which has 106 feet of drive pipe, but the rock was struck at slightly less than 100 feet, there being a few feet of rotten rock below the drift. At the Jennings well the drive pipe is 76 feet in length, but it extends a few feet into the rotten surface of the limestone. The difference in thickness of drift is not due to knolls or ridges, but to inequalities of the underlying rock surface, the uplands in the vicinity of Mount Oreb having now a very flat surface.

Between Mount Oreb and Williamsburg there are rock exposures in shallow ravines, the altitude of the rock surface being somewhat higher than at Mount Oreb. A soil was frequently observed between the silt and underlying till, at about 3 feet below the surface. At Williamsburg the East Fork of Little Miami River has rock bluffs rising on each side of the creek to a height of about 20 feet, above which there is about 50 feet of drift,

mainly till. A short distance from Williamsburg, on the road toward Bethel, rock outcrops up to a level only 15 or 20 feet below the level of the uplands, or much above the level of the rock surface in East Fork Valley. The peculiar drift structure at Bethel was noted above (p. 273). Granite bowlders are found on the surface in the vicinity of Bethel, which are, in some cases, 8 or 10 feet in diameter. Similar bowlders are reported from the vicinity of Russellville, in Brown County.

East of Bethel, near Hamersville, on an elevated ridge standing about 975 feet above tide, the drift is thin, being only 10 to 20 feet in thickness, and the altitude of the rock surface is 90 to 100 feet higher than at Bethel.

The drift is thin on the uplands on either side of White Oak Creek, in the vicinity of Georgetown, scarcely exceeding 20 feet.

The drift at Winchester has a thickness of only 10 feet in the eastern part of the village, but exceeds 20 feet in the northern and western parts.

Drift exposures are numerous between Winchester and Seaman, the first railway station toward the east, but farther east there are only scattering patches of drift or occasional bowlders.

The general thickness of the drift along the Baltimore and Ohio Railroad in Brown and Clermont counties and between that railroad and the outer Wisconsin moraine is 20 feet or less, or an amount scarcely half that found in a trip through a tract 12 to 20 miles to the south. This thickening does not, however, assume the form of a ridge, but as previously noted, simply serves to fill up preglacial inequalities of surface to a somewhat uniform level.

From the Little Miami Valley westward across Hamilton County, Ohio, there is a nearly continuous sheet of till, the thickness of which on the uplands seldom exceeds 20 feet, but in lowlands and valleys sometimes reaches 100 feet or more.

South of the Ohio River there is not so continuous a sheet of drift. Pebbles and bowlders of Canadian derivation constitute one of the conspicuous features. There are also deposits of a sandy, or more frequently clayey character, through which Canadian rocks are sparingly distributed. In these deposits many local rock fragments occur. They usually bear but slight resemblance to ordinary till, though the presence of granite or other distantly derived pebbles is evidence that they were acted upon by the ice sheet. They appear to be in the main only the slightly disturbed

residuary clays formed by a dissolution of the surface limestones of that region. Aside from the deposits noted there are occasional beds of coarse gravel and cobble. The bowlders, as above noted, are usually a foot or less in diameter, but they occasionally reach a diameter of 3 or 4 feet.

In his report on the glacial boundary[1] Wright notes the occurrence of till in Campbell County, Ky., on the slopes facing the Ohio River. It extends to an elevation of 350 to 400 feet above the river, but no till or granite pebbles were found on the dividing ridge between the Ohio and Licking rivers, whose general altitude is about 400 feet above the river. He describes a stiff clay deposit containing granite pebbles in western Kenton County at points 7 miles south of the Ohio, and also at a railroad cut at Erlanger, the altitude at Erlanger being 475 feet above the river. Granitic bowlders were also noted in pebbly clay. The heaviest deposits of glacial material yet observed on the Kentucky side of the river are the Split Rock conglomerate in the Ohio Valley and a similar deposit a few miles southeast of Split Rock, both of which were discussed above (p. 261).

On the north side of the Ohio, in the vicinity of Cincinnati, the Illinoian drift, as previously remarked, forms a nearly continuous sheet both on the uplands and lowlands. So far as observed the only localities in which the drift is patchy or attenuated are along the brow of the Ohio bluffs and on some of the sharp ridges bordering the Great Miami. Here in places there are only scattering pebbles and bowlders. The upland drift, beneath the surface coating of silt, consists almost entirely of ordinary till, there being but little sand or gravel associated with it. The lowland drift is more variable, there being much sand, gravel, and pebbleless clay as well as till. The upland drift ranges from a thin coating up to a deposit about 50 feet in thickness with a general average of about 20 feet. The lowland drift usually exceeds 50 feet, and in the larger valleys a thickness of about 200 feet is attained. The till has a brown or yellow color to a depth of 10 or 15, and occasionally 20 or 25 feet. Below this depth it has a blue or gray color.

Where there has been no erosion the bowlders are entirely concealed by the silt, and they are not numerous on the hillsides or in places where erosion has removed the silt covering. The fact that few bowlders and

[1] Bull. U. S. Geol. Survey No. 58, 1890, p. 63.

gravel deposits are to be seen in the district south of the outer Wisconsin moraine was noted by Professor Orton in his reports on the counties of southwestern Ohio, though he did not recognize the moraine and consequently indicated the boundaries of the extramorainic tract in only a general way. Thus, in his report on Warren County, he calls attention to the fact that the southeastern townships are covered with white clays, while in the northern townships bank gravel is met with on the highlands as well as in the valleys.[1] In his report on Butler County (a county lying mainly within the district covered by the Wisconsin ice invasion) he calls attention to the bowlders that occur plentifully at all altitudes, while in his reports on Hamilton County (a county lying mainly outside the outer Wisconsin moraine) he calls attention to the scarcity of the bowlders. In the report of the Indiana survey on the southeastern counties of Indiana similar statements are made concerning the drift in nearly every county lying outside this moraine, it being noted that bowlders are seldom seen except along ravines, and that the uplands contain scarcely any bank gravel; while in reports on counties traversed by the moraine or lying north of it, the presence of bank gravel and surface bowlders receives frequent comment. The contrast between the surface features of these districts is, therefore, so striking that it was remarked long before the moraines were recognized.

Some of the exposures of lowland drift in southwestern Ohio merit special mention. One of the most extensive is found along the line of the Cleveland, Cincinnati, Chicago and St. Louis Railway, between North Bend and Cleves. Here there is a gap in the rocky ridge which lies between the Great Miami and Ohio rivers, in which there has been a drift filling to a height of 150 to 170 feet above these streams. The railway has made a cut 80 feet deep in the summit of the gap without encountering rock; while a well in North Bend near the south end of the cut does not reach rock at a depth of 73 feet, though its bottom is nearly as low as the present river bed. Within 80 rods either side of this cut the limestone ledges rise to a height of 200 feet or more, while on portions of the dividing ridge between the Miami and Ohio rivers the rock surface reaches an altitude of fully 400 feet above these streams. Both the railway cutting and the well are mainly through till. There are, however, assorted beds associated with the till. In one place on the west side of the track a funnel-shaped sand

[1] Geology of Ohio, Vol. III, p. 387.

deposit completely displaces the till, extending from the top to the bottom of the cutting. Its beds dip and curve greatly, conditions which seem to suggest that they were deposited beneath the ice sheet and disturbed by its movement. There are also horizontal breaks in the till with thin beds of assorted material between, features indicating an alternation of aqueous with glacial deposition. The upper surface of the till is eroded and a bed of assorted material 6 or 8 feet in thickness rests unconformably upon it. This assorted material is principally coarse sand, but is, in places, of a gravelly character, and it grades upward into a silt or fine sand nearly free from pebbles. Between this assorted material and the underlying till there appears in places a dark-colored band, which is sometimes of a peaty character and contains bits of wood but quite as often consists simply of a stain on the pebbles. In one place there was found a thin bed of very fine sand between the peat and the underlying till, and in this sand minute gasteropod shells were embedded. The evidence is, therefore, decisive that the assorted material is a later deposit than the till, but its precise age is not yet determined. The silt which overlies it and forms the surface of this lowland district does not appear to be of markedly later age than the sand and gravel, there being no distinct line of separation or unconformity between them. The preservation of the peat beds and the shell-bearing sands, as well as the sandy character of the assorted beds overlying them, seems to indicate that the depositing waters had not violent movement. Since the assorted beds stand only 40 to 50 feet above the terraces which were formed in connection with the Wisconsin ice invasion and at a point where the Great Miami makes an abrupt change in its course, the question arises whether an unusual flood or a temporary ice gorge may not have caused the water to rise to a sufficient height to pass across this low gap into the Ohio and thus produce this deposit. There appears to be nothing in the character of the beds to oppose this interpretation, yet it may not prove an adequate one.

In the abandoned valley north of Cincinnati connecting Mill Creek and the Little Miami River (see Pl. V) there are several exposures of the upper portion of the drift, from which it appears that the structure presents considerable variation. The structure of the lower portion of the drift, as shown by well sections, is also variable, there being in places heavy beds of blue silt, while in other places there is gravel, and in still others till.

The opinion is expressed by Orton, in the Ohio reports, that this lowland is filled with alluvium, and Wright's reports contain the same opinion, though the latter makes mention of till in this district. The numerous exposures, some sections of which are given below, will make it evident that the drift here is glacial rather than alluvial.

This lowland tract carries a few undulating surface swells 10 to 15 feet and occasionally 20 feet in height, whose forms could scarcely be produced by erosion. A good illustration may be seen in the southwestern part of Madisonville, on the west side of Columbia avenue, the residence of E. S. Emerson being built upon a swell that stands nearly 15 feet above the bordering tracts. A cistern at Emerson's shows the swell to be composed of till. This lowland tract is drained by a small stream (Dutch Creek) leading eastward into the Little Miami River, and a score or more of exposures along the banks show ordinary till. Beds of silt are associated with the till, but as often as otherwise they underlie it, except in the case of the surface silt, which forms here, as on the uplands, a continuous capping for the till.

In a ditch on the east side of the electric railway, between the Zoological Gardens and St. Bernard, and near the south border of this lowland tract, is an exposure with a silt deposit 3 to 4 feet, beneath which is fine sand, somewhat contorted and wavy, thickness 3 to 4 feet; then follows a yellow till, very stony, about 20 feet in thickness, beneath which is a pebbly laminated clay of deep-blue color, in which the bedding has contorted or disturbed lines. This blue stratum is exposed to a depth of 25 or 30 feet.

On Rose avenue, in St. Bernard, a few rods east of the canal, the following beds are exposed:

Section on Rose avenue, St. Bernard.

	Feet.
1. Clayey sand	4–5
2. Pebbly clay of yellow color, doubtfully classed as till	3–4
3. Pebbly clay of dark-brown color	1–2½
4. Fine calcareous clay loam, nearly free from pebbles, porous at top, and of sufficient coarseness in places to be called a sand, but grading below into a compact laminated clay, color varying from yellow to blue, but mainly blue near base	7–8
5. Ordinary yellow till	3–4
6. Ordinary blue till, exposed	2–3

In the vicinity of Bond Hill there are sand deposits which extend east nearly one-half mile from Mill Creek Valley, and lie north of the lowland tract under consideration. They reach a height of 45 to 50 feet above the

plain in Mill Creek Valley, immediately west and about 160 feet above the Ohio River. The method of deposition of this sand is not clearly understood. Occasional small pebbles, one-eighth inch or more in diameter, contained in the sand seem to indicate that it is not entirely a wind-drifted formation. The till with its capping of silt passes beneath this sand, a fact implying that the sand is more recent than the silt. The sand is probably connected in some way with the floods attending the Wisconsin ice invasion. The features suggest that it may have been deposited during a rise of water occasioned by an ice gorge in the valley of Mill Creek below Carthage, the width of the valley being somewhat reduced in passing Walnut Hills just before it enters the Ohio Valley.

In passing through this lowland tract the Panhandle Railway makes numerous cuttings 10 to 20 feet deep, which in nearly every instance expose a silt 4 to 5 feet thick, below which there is ordinary till. In one cut near Pleasant Ridge there is a bed of assorted material (sand and gravel) between the yellow and blue tills, but in the majority of cuttings the yellow till grades downward into the blue.

Within the village of Madisonville there is an abrupt change in the substrata, the western portion of the village being underlain by till to a depth of 40 to 50 feet or more, while the eastern is underlain by gravel at slight depth. Above the gravel there is in some places only a silt deposit; in other places there is a deeply oxidized (reddish-brown) clay carrying a few pebbles. The age of the reddish clay is not known, the situation being such that it is difficult to determine. It occupies a basin or slightly depressed tract and may, therefore, have received contributions in post-glacial times by the wash from the neighboring highlands. It is also sufficiently low to have been flooded by the Little Miami, at least down to the time of the Wisconsin ice invasion. The bearing of these conditions upon the question of the Madisonville chipped stone, which was found at the base of this red clay, was discussed by the writer some years ago, and the conclusion was reached that the deposit can not be referred with certainty to glacial agencies; in fact it may be much more recent than the last stage of glaciation.[1]

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[1] Supposed Glacial man in southwestern Ohio, by Frank Leverett: Am. Geologist, Vol. XI, 1893, pp. 186–189.

The following section was obtained in the southwest part of Madisonville, where a street (Columbia avenue) has been graded down:

Section on Columbia avenue in Madisonville, Ohio.

	Feet.
1. Clay or silt, nearly free from pebbles, color light brown	3–4
2. Pebbly clay of dark-brown color, slight traces of bedding, with crumpling and disturbance	4–6
3. Brown till with blue streaks	4
4. Gravel and sand in horizontal beds, exposed	7–8
Total	20–22

A short distance west the same street grade shows a change in the till (No. 3) to a fine laminated clay, while the underlying bed becomes disturbed.

Just north of Batavia Junction, where this lowland tract opens into the Little Miami Valley, there is a bluff rising to a height of 80 feet above the station or about 140 feet above the Ohio. The following beds are exposed:

Section near Batavia Junction, Ohio.

	Feet.
1. Sandy surface deposits	5–10
2. Yellow clay containing blocks of local limestone	15–20
3. Fine sand	15
4. Gravel, medium to coarse	40

It seems not improbable that the gravel beds here exposed extend north into Madisonville, there being nothing in the topography to oppose this view and the distance being only a mile. A short distance west of Batavia Junction the Wisconsin gravel appears in the form of terraces along the face of the bluff, the upper terrace being about 40 feet below the level of the border of the lowland tract under discussion.

Calcareous nodules were observed at many points in this lowland tract in connection with the silts which underlie or replace the till, but they are not common here or elsewhere in connection with the silt that overlies the till and forms the surface of the uplands and are seldom found in the till itself. An exposure was noted, however, just east of the gate of the Zoological Garden and near the top of the north slope of the Walnut Hills Ridge, where nodules appear in a pebbly clay just below the silt, the section exposed being:

Section near Zoological Garden in Cincinnati, Ohio.

	Feet.
1. Silt of pale yellow color	4
2. Clay containing few pebbles, but thickly set with calcareous nodules	2
3. Ordinary yellow till, exposed	6–8

Sections of several wells along Mill Creek Valley are given in the discussion of the early Wisconsin drift (Chapter X). The greater part of the drift is probably Illinoian, as appears in that discussion.

The portion of the Illinoian drift sheet covering southeastern Indiana was the subject of only a hasty reconnaissance by the writer, and very few detailed sections can be furnished. Numerous exposures were found in which yellow till extends to the rock, the distance to rock on uplands being generally 20 feet or less. Well sections published in the Indiana reports, which throw light upon the deeper parts of the drift are here reproduced:

Section of Van Osdel well in Ohio County, Ind. (sec. 6, T. 3, R. 2 W.).

	Feet.
1. Soil and clay	22
2. Yellow sand, quite hard or cemented	9
3. Blue clay, hard, without pebbles	1½
4. Black soil containing rotten leaves, twigs, and wood, thought to be walnut	1½
5. Coarse sand, gravel, and shelly stone	9
6. Hard, blue limestone	1
Total	44

Section of Gorden well in northwest Switzerland County (sec. 4, T. 5, R. 12 E.).

	Feet.
1. Soil and clay, pale in lower part	22
2. Blue mud resembling recent alluvium	6
3. Black soil containing leaves, cedar wood, and ocherous particles	3
4. Small stones closely packed together	1
Total	32

Wells in that vicinity often enter rock at 10 to 14 feet, but a neighboring well struck leaves and poplar bark at 32 feet. It is thought that the bottom bed in the Gordon well is native rock. In the vicinity of Paris Crossing, in the extreme southern part of Jennings County, buried timber is often found in digging wells on land 60 to 70 feet above the bed of Graham Creek. From one well, sunk by Mr. John F. Files, it is estimated that at least a half cord of wood was taken, at a depth of 32 to 40 feet. The wood appeared to be birch, and specimens were sent to the State museum. The wood was much crushed and twisted, but it was found suitable for fuel, and was made use of by Mr. Files. The following is the section of the beds penetrated:

Section of Files well, near Paris Crossing, southern Jennings County.

	Feet.
1. Light-colored clay with darker shades below	10
2. Ocher-colored clay with flint pebbles, increasing in hardness toward the bottom	19
3. Very hard bed of clay and gravel	2–3
4. Sandy blue clay with water; also limbs, twigs, and roots of trees	7–10
Total	38–42

The ingress of water prevented the deepening of the well, and the wall was commenced on the driftwood at its bottom. A well at South Milan, in eastern Ripley County, 54 feet in depth, did not enter rock, though quarries are opened in that vicinity at about the level of the well mouth. The following is a section of the well made by the railway company:

Section of railway well at South Milan, Ind.

	Feet.
1. Light-colored clay	10–14
2. Yellow clay with flint, gravel, and fossil corals	12
3. Blue glacial clay	12
4. Coarse yellow sand with recent shells and water	8
5. Blue clay and muck containing roots and limbs of trees	8
Total	54

Statistics concerning wells were obtained at several villages on the uplands in these southeastern counties of Indiana, as follows: At Versailles, the county seat of Ripley County, wells are obtained at depths of 18 to 25 feet in the upper part of the limestone. At Osgood they are usually obtained near the base of the drift at depths of 9 to 15 feet. Occasionally they are drilled to a depth of 100 feet or more in the northern part of Ripley County. At North Vernon, in Jennings County, wells are obtained usually at depths of 12 to 35 feet, the majority being about 25 feet; they enter the rock a few feet. At Charlestown, formerly the county seat of Clark County, many wells are obtained at a depth of 30 to 35 feet, usually in the Corniferous limestone. A few, however, reach this depth without entering rock. In wells where drift 25 to 30 feet in thickness is penetrated it is common to find a blue mud carrying tree trunks or small pieces of wood near the base of the drift. Rock is ordinarily struck in this village at about 12 feet. There are four very strong springs within the corporate limits of the town, which are used by many of the residents. At Scottsburg, the county seat of Scott County, wells are usually obtained at 25 to 35 feet or less. A gas-well boring near the railway station penetrated 47 feet of drift, as follows:

Section of drift in gas-well boring at Scottsburg, Ind.

	Feet.
1. Yellowish white clay, nearly pebbleless	15
2. Sand	5
3. Blue till	27
Total	47

In the Whitewater Valley several borings for gas have been made outside the limits of the Wisconsin ice invasion. They fall within the limits of a terrace of Wisconsin gravel, but as the Wisconsin gravel probably extends little, if any, below river level a large part of the material is thought to be Illinoian. A boring at the brickyard in the south part of Brookville shows the rock floor to be about 180 feet below the low-water level of the stream, or but 440 feet above tide. Three other borings in the valley near Brookville enter rock at a level about 125 feet below the river, or 495 feet above tide. A gas boring near Cedargrove, also in this valley, penetrates 154 feet of drift and enters rock at about 450 feet above tide. At the mouth of the river the rock floor is less than 400 feet above tide

SECTION III. CHARACTER OF THE OUTWASH.

GENERAL STATEMENT.

In the western part of the region, from near Louisville, Ky., eastward to near Maysville, the ice sheet at its culmination occupied the Ohio Valley so completely that drainage must have been greatly obstructed. As indicated above, the deposits appear to have been very uneven; parts of the valleys apparently received but little drift, while other parts were filled to a height of 150 to 200 feet above the present stream. The filling is also variable, being in places a fine silt, in other places an ordinary till, in other places assorted sand and gravel, and in still other places a conglomerate with a large number of coarse stones in a matrix of clay or fine sand. In some of the valleys in central Ohio a terrace composed of well-assorted sand and gravel appears, which is probably of Illinoian age. Reference has already been made (p. 102) to the terrace in the Scioto Valley. This and similar terraces in valleys farther east will now be considered. The discussion begins with a terrace in Sandy Creek Valley, that being the easternmost valley in which there appears to be good evidence of an outwash of Illinoian age. Valleys to the west are then taken up in succession.

SANDY CREEK VALLEY.

About 1 mile east of Minerva, Ohio, Sandy Creek, a tributary of Tuscarawas River, leaves the Wisconsin drift and enters what appears to be an unglaciated tract. For several miles below the limits of the Wisconsin drift it seems to have only one terrace above the flood plain, and this is in all probability of Wisconsin age. Near Waynesburg, Ohio, a higher

terrace appears, which seems to be much older than the Wisconsin terrace. It stands about 70 feet, while the Wisconsin terrace in that part of the valley rises scarcely 40 feet above Sandy Creek. It is preserved only in a recess on the south side of the valley, and there has a much more eroded surface than the Wisconsin terrace. It contains a sandy gravel which shows a greater degree of weathering than the Wisconsin gravel, and it has been opened extensively by the railway company to obtain gravel for ballast. The entire deposit is deeply weathered and many of the stones are very rotten. A few granite and quartzite pebbles, 3 inches or less in diameter, were found after prolonged search, but there is a much smaller percentage of such rocks than in the gravels of Wisconsin age found on the lower terrace along the creek.

The valley was examined below Waynesburg as far as Sandyville, but no other remnants of the old gravel were observed.

The occurrence of this old gravel suggests that the border of the Illinoian drift sheet may lie not far back to the north; but, as indicated in the discussion of that drift, no exposures have been noted outside the Wisconsin drift in that part of Ohio.

TUSCARAWAS AND TRIBUTARIES.

No other remnants of such old gravel have been observed on the Tuscarawas or its tributaries, though the valleys have received only a hasty examination, and some of them have received no attention. The same is true of the valley of Killbuck Creek, a tributary of Walhonding River. The Walhonding emerges from the old or Illinoian drift a few miles above its mouth, but examinations have not been carried down the valley sufficiently to determine whether there was a notable outwash. Wahatomaka Creek also emerges from the old drift some distance above its mouth, but the portion outside the drift border has received no attention. We accordingly pass to the next valley to the west, Licking River, and consider its outwash and that of its continuation, Muskingum River.

LICKING-MUSKINGUM VALLEY.

As noted in the discussion of the drift border, a great dam was built across the old westward line of discharge of the Muskingum, at Hanover, Ohio, which stands about 100 feet above the portions of the valley on each side, and perhaps 300 feet above the rock floor of the old valley. While

the dam was accumulating a lake probably occupied the valley to the east. The filling is largely a fine silt of blue color, capped by a few feet of gravel and sand. The amount of filling has been sufficient to cause a new channel to be opened by the Licking for a short distance in the vicinity of the drift border.

In the tract lying between the Licking and the old valley of the Muskingum, east from the drift border as far as the present valley, there has been a general filling up of valleys, not only on the main lines of drainage, but also on the tributary lines. Much of the filling is a fine silt, but the surface, as in the dam at the drift border, is of coarser material. In some of the tributary valleys small drift pebbles have been observed on the slopes up to a level 25 feet or more above the flat valley bottoms, a feature which seems to indicate that the region has been submerged to levels above the valley bottoms. It is suggested that the prevailing west winds may have carried cakes of ice laden with pebbles from the vicinity of the drift border eastward into these valleys, passing, in some cases, over low divides, and thus distributing them outside the range of the present system of drainage.

The glacial lake which was held in this portion of the Muskingum Valley discharged southward to the Ohio across the old divide south of Zanesville. The volume of its discharge was probably much greater than that of the present Muskingum, since it appears to have carried nearly all the drainage of the ice field in northeastern Ohio. The high-level gravels below the old divide at McConnelsville, and at points farther down the valley, may prove to have been deposited by the glacial waters crossing this divide. But as yet this is merely a matter of conjecture. The gravel at McConnelsville has an aged appearance quite similar to that of the glacial gravels connected with the Illinoian drift, and decidedly in contrast with the fresh gravels of Wisconsin age, which occur at lower levels in the valley. In this connection it may be remarked that gravel of Wisconsin age has been deposited in such large amount along the line of the Licking below Hanover and along the entire length of the Muskingum that the outwash from the earlier ice field has been rendered rather obscure, except at the great dam near Hanover.

HOCKING VALLEY.

The Hocking Valley appears to have been a line of vigorous discharge for glacial waters during the Illinoian ice invasion, there being a large amount of gravel and cobble in its middle and lower courses outside the limits of glaciation, which seems to have been derived from the Illinoian drift. Much of the gravel has been carried beyond the supposed old divide below Sugargrove, there being extensive remnants in the vicinity of Logan and Haydenville, and also north of Athens. The old gravel has been largely removed in the part of the valley above the divide down to a level at least as low as the Wisconsin terraces, but it can be traced up to the Illinoian drift border. Reference was made in the discussion of the drift border to a terrace on the lower course of Clear Creek that leads down to the Hocking and also to the old gravel in the Hocking Valley at Lancaster. These seem to be near the head of the glacial drainage.

The altitude of the gravel terrace decreases in passing down the valley at about the rate of fall in the river, and the terrace stands 80 to 100 feet above the stream. At Lancaster the gravel has an altitude of nearly 900 feet, at Logan scarcely 800 feet, and near Athens about 700 feet above tide. The general elevation is about 50 feet above the terraces of Wisconsin age in the valley.

The gravel varies greatly in coarseness, some portions being rather fine with a liberal admixture of sand, while other portions are a coarser gravel and cobble. On the whole the material is coarser than is usually displayed by terraces connected with the Illinoian drift. It is often firmly cemented into a conglomerate, the cement being usually calcareous, but in some cases ferruginous. As noted above, this conglomerate is used at Lancaster in stone fences. Near Logan its outcrops on the face of a terrace bear a strong resemblance to rock ledges.

Granite, quartzite, and other Canadian rocks, though not so abundant as in the gravels of Wisconsin age, are well represented all along the terrace. Some of these rocks, in a remnant of the terrace near the schoolhouse in the north part of Logan, are 5 or 6 inches in diameter. They are nearly as coarse in the terrace north of Athens.

In the vicinity of Logan a valley fully one-half mile wide seems to have been filled with this old gravel from a level about 75 feet below the river to a level fully 80 feet above it. For a distance of 3 miles below

Logan remnants are very extensive, occupying one-third to one-half the width of the old valley. From that point to Chauncey nearly all the gravel has been removed down to a level as low as the Wisconsin gravel; but between Chauncey and Athens a section of the old valley is abandoned, and more than a square mile of the gravel filling is preserved. Below Athens no remnants of the old gravel were noted. Possibly the deposit was not carried in large amount farther down the valley than the abandoned section above Athens.

SALT CREEK VALLEY.

As indicated in the discussion of the drift border, the North, or main, Fork of Salt Creek appears to have held a small glacial lake during the deposition of the Illinoian drift, into which but little material except fine silt was carried. The lake discharged across an old divide near the point where the present stream passes from Hocking into Vinton County, into a valley that opened southward to the Scioto, but it seems not to have carried much material into that valley.

The South Fork of Salt Creek, though lying apparently entirely outside the limits of glaciation, is so situated that the glacial accumulations on the Scioto at the mouth of the creek held a lake in the creek valley into which the glacial waters passed, and at the head of which they opened a passage southward to the Ohio. This lake received a large amount of fine calcareous sediment, the depth at the present divide between Salt Creek and Symmes Creek near Camba being not less than 90 feet.

SCIOTO VALLEY.

Attention was called in the discussion of the Illinoian drift border to a prominent gravel terrace on the Scioto, which heads at the glacial boundary east of Chillicothe. This terrace, which at its head stands about 100 feet above the Scioto, has been built up at that point from below river level. Passing southward, down the valley, one finds the glacial gravel covering a series of rock shelves, which show a slight increase in altitude in that direction. It declines in altitude about 50 feet in passing from the glacial boundary to the mouth of the Scioto, where it barely comes to the level of the rock shelves. From more than 100 feet opposite Chillicothe the depth of the gravel becomes reduced to but 15 feet at Coopersville, near the line of

Pike and Scioto counties, about 30 miles below. The surface in that distance falls from fully 700 feet above tide to 650 feet or less, while the rock shelf, or old valley floor, rises from below 600 feet to fully 625 feet. The material in this terrace varies from a well-assorted gravel of medium coarseness to a sandy and clayey gravel very imperfectly assorted. As a rule, the gravel contains a large amount of sand. The current was probably moderate except, perhaps, on the immediate borders of the ice sheet. The gravel, like the drift from which it was derived, contains only a few Canadian rocks, yet they have been found as far down as Coopersville.

In an old oxbow back of Lucasville, discussed in Chapter III, no glacial deposits were noted, but pebbles were found on the inner slope up to a level above the probable limits of the filling by glacial gravel. These pebbles, as well as the material in the bottom of that oxbow, may be older than the glacial gravel. The altitude of the bottom of the oxbow is fully as great as the glacial gravel at Coopersville, and no Canadian rocks were found in it after prolonged search.

MIDDLE AND LOWER OHIO VALLEY.

The portion of the Ohio Valley which was covered by the ice sheet, from near Maysville down to the vicinity of Louisville, Ky., received a large amount of drift, some of which is evidently waterlaid. It is not, however, so distinct an outwash from the ice sheet as that found in valleys to the east, already discussed. Much of it was probably deposited as directly by the ice sheet as the till of the bordering uplands. It has accordingly been treated in connection with the drift sheet. By reference to these descriptions, it will be seen that the filling varies greatly in constitution, as is to be expected in a partially obstructed valley.

The encroachment of the ice sheet on a part of the Lower Ohio at the Illinoian stage of glaciation may seem to oppose the view that some of the gravel carried down the Scioto was of Illinoian age. It seems probable, however, that the drainage through the Ohio was obstructed for only a brief time if at all. The glacial boundary at its farthest point extends but 10 or 12 miles beyond the Ohio, and generally but 2 to 5 miles. It is not certain that so slight an extension could cause complete damming.

Furthermore, the ice sheet extended beyond the Ohio during only a small part of the Illinoian stage of glaciation, thus leaving the valley open

most of the time, except for the drift filling, and this was not sufficiently high to greatly impede the flow of water from the upper part of the Ohio and its tributaries. The filling is generally below the 600-foot contour, which is 100 feet lower than the head of the gravel terrace on the Scioto, and perhaps 25 feet lower than the gravel filling near the mouth of the Scioto.

Below the limits of glaciation the Ohio Valley has received only a hasty examination, and no deposits have been found that seem to be referable to the Illinoian outwash. The examination has, however, not been sufficiently complete to make certain that such deposits do not exist, and it is possible that some terraces which have been referred provisionally to the Wisconsin may prove to be older.

CHAPTER VII.

THE SANGAMON SOIL AND WEATHERED ZONE.

After the Illinoian stage of glaciation the surface of its drift sheet became weathered, and a black soil was formed on the level or poorly drained portions. This weathering and the forming of a soil continued for a considerable period, as is apparent from the state of decay of the pebbles and the leaching of the till, there having been usually a complete leaching of the lime from the finer part of the till to a depth of several feet, accompanied by a nearly complete dissolution of limestone pebbles.

This weathering has not continued to the present day, for the surface of the Illinoian has received a coating of silt several feet in depth, which now prevents further weathering. This silt deposition and interruption of the weathering, as indicated below, are thought to have occurred in connection with the Iowan stage of glaciation, in which case the soil and weathered zone stand for an interglacial stage between the Illinoian and Iowan glacial stages.

The name Sangamon has been suggested for this interglacial stage by the writer because of the excellent development of the soil in the Sangamon River drainage basin, in central Illinois, and because the exposures there were among the earliest recognized in this country.[1]

The Sangamon soil and weathered zone may be seen beneath the surface silt in thousands of exposures in southeastern Indiana and southwestern Ohio, for the general thickness of the silt is only 4 or 5 feet. Farther north there are, in addition to the silt, the heavy deposits of Wisconsin drift, which have buried the soil and weathered zone to such a depth that it is rarely exposed. However, a few exposures have been found in the deeper valleys, and wells not infrequently penetrate both the silt and the soil under the Wisconsin drift.

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[1] The Sangamon soil and weathered zone, by Frank Leverett: Proc. Iowa Acad. Sci., Vol. V, 1898, pp. 71–80; also Jour. Geol., Vol. VI, 1898, pp. 171–181. Numerous instances of occurrence within the limits of the Illinois glacial lobe are cited in Monograph XXXVIII of this Survey.

It is this soil which attracted the attention of Orton in his examination of wells near Marshall, in Highland County, Ohio,[1] but the soil there is within the limits of the Wisconsin drift. It is probable that the deposits of peat below the Wisconsin drift near Germantown, in Montgomery County, Ohio, also brought to notice by Orton,[2] are referable to the Sangamon. In fact, the great majority of buried soils reported in Ohio, Indiana, and Illinois appear to be at this horizon. The soil attracts attention more effectively when found at considerable depth than in places where it is covered by only a few feet of silt. One often passes it in the latter situations without realizing that it is really at a lower horizon than the surface soil, for the surface soil is liable to be washed down the slope below the level of the Sangamon soil. A careful inspection, however, will place beyond question the frequent occurrence of the Sangamon soil. In many cases it can be traced back along ditches until it passes beneath the surface silt, but where this can not be done an examination of the constitution of the Sangamon soil will reveal the presence of pebbles, which distinguish it from the pebbleless surface soil.

The Sangamon soil, in the region under discussion, does not commonly show a black color, though exposures of such a color are met with in all parts of the region. The evidence of a land surface is more generally found in the deep-brown color and weathering or soil-producing disintegration of the upper part of the till. The deep brown changes gradually below to the ordinary yellow color of oxidized till, but at top it terminates abruptly at the base of the overlying silt. The color of the silt being much lighter than that of this brown soil, the contrast is very marked. The deep-brown color extends usually to a depth of 2 feet or more, while leaching and discoloration are noticeable to 6 or 8 feet. The amount of discoloration is somewhat greater than is commonly found at the surface of the Wisconsin drift, and numerous comparisons of the Sangamon soil with the post-Wisconsin soil lead to the opinion that the Sangamon involved more time than has elapsed since the culmination of the Wisconsin stage of glaciation. The same opinion is reached upon comparing the amount of leaching. On the Illinoian drift it is rare to get a response with acid within 6 to 8 feet of

[1] Rept. Geol. Survey Ohio, 1870, p. 266.

[2] Am. Jour. Sci., 2d series, Vol. L, 1870, pp. 54–57, 293. See also Rept. Geol. Survey Ohio, 1869, pp. 165–169.

the surface, whereas in the Wisconsin drift the leaching has seldom been carried to so great a depth as 6 feet. It seems clear from the position and relations of this old land surface that the leaching took place before it was buried under the silt. In view of these facts, this may safely be considered one of the main intervals of deglaciation.

The erosion of the Illinoian drift in the Sangamon interglacial stage was not so conspicuous a feature as the weathering. This is true not only in the region under discussion, but also in the region to the west, covered by the Illinois glacial lobe. The channeling seems to have been shallow and broad wherever new lines were opened, while the old lines, being already largely open, suffered but little excavation. These features indicate that drainage conditions were less favorable than now, but they should not be cited against the evidence of a long interval derived from the leaching and weathering of the surface. The conditions for erosion seem to have become worse rather than better toward the close of the Sangamon interglacial stage, and in the stage which followed, as indicated below, erosion was either suspended or became so feeble as to allow silt to accumulate on the surface.

CHAPTER VIII.

THE LOESS AND ASSOCIATED SILTS.

GENERAL STATEMENT.

On the borders of the Mississippi and its main tributaries there is a very porous silt which overlies the Sangamon soil and weathered surface of the Illinoian drift sheet, and which has long been known as loess. It is commonly calcareous to a marked degree, though its main ingredients are siliceous and argillaceous particles. A series of chemical, mineralogical, and mechanical analyses appear in Monograph XXXVIII of this Survey. Portions of the loess are highly fossiliferous, with a fauna composed chiefly of terrestrial species of mollusks, but containing also species which inhabit ponds, and occasionally a fluviatile mollusk. Lists of the fossils are also given in Monograph XXXVIII.

On the uplands back from the Mississippi and its main tributaries, and also along the minor tributaries, there are silts of more compact texture than those which border the valleys. Mechanical analyses of samples collected in Illinois, also appearing in Monograph XXXVIII, show that there is a larger proportion of very fine particles in these compact silts than in the loess bordering the valleys, but that in many respects they are similar. The porous loess does not contain coarser particles than are found in the compact silt.

DISTRIBUTION.

The compact silt extends eastward in a practically continuous sheet from Illinois over southern Indiana, southern Ohio, and neighboring portions of Kentucky and West Virginia, and is the surface deposit as far north as the border of the Wisconsin drift sheet. It is known to underlie the Wisconsin drift, numerous exposures having been found beneath that drift.

This silt has long been recognized in the glaciated districts of southwestern Ohio and southeastern Indiana. In the Ohio reports it is referred to as the "white clay," and in the Indiana reports as "slash land." It has

not been known so long that a similar silt extends outside the limits of the Illinoian drift. Wright has called attention to a silt on Beech Flats, in Pike County, Ohio, which was cited as an extra glacial material, but it now appears to be underlain throughout by glacial deposits.[1] In the writer's examinations in southeastern Ohio and neighboring parts of West Virginia and Kentucky, in 1896, it was found that the silt occurs at least as far east as Parkersburg, W. Va. Examinations in the Beaver Valley, in Pennsylvania, in 1898, as indicated on page 252, have raised the suspicion that it occurs there. It may also occur on the Monongahela and its tributaries, for the terraces there are in many places capped by a compact silt several feet in depth. This, however, is merely a conjecture. Its limits will not be easy to determine, for it is so thin that it is likely to be preserved only on comparatively flat areas where erosion has been very slight. Wherever flat uplands appear in southeastern Ohio from the glacial boundary eastward to Parkersburg, W. Va., the silt capping is clearly recognized. It is especially noticeable in parts of Morgan County, near McConnelsville, which are underlain by limestone, for the silt contrasts more strikingly in color with the residuary products of the limestone than with those of sandstone.

The extent of this silt northward beneath the Wisconsin drift is undetermined. It has been found at some distance back from the border, both in southeastern Indiana and in southwestern Ohio.

THICKNESS OF THE SILT.

The thickness of the silt on the uplands of southeastern Indiana, northern Kentucky, and southern Ohio, where it overlies the Illinoian drift, averages scarcely 5 feet, and seldom reaches 10 feet. As the exposures are mainly on slopes where more or less removal has occurred, the thickness seems to be only 2 or 3 feet, but the wells or excavations on flat uplands correct this interpretation and show it to be about 5 feet. The thickness varies but little from place to place, though it seems to be less on uplands near the Ohio Valley than farther north near the limits of the Wisconsin drift. This difference may be due to greater erosion on the borders of the Ohio, where the surface is more completely dissected than at points some distance back. But there is also a strong probability that some silt has been deposited as an outwash along portions of the Wisconsin border.

[1] Bull. U. S. Geol. Survey No. 58, 1890, pp. 92-96.

The thickness of the silt on uplands outside the limits of the drift is even less than on the drift, though it probably falls short but a foot or two. The estimates are mainly from exposures on slopes, there being few opportunities to learn its thickness on the level upland. It should be borne in mind, also, that the country outside the limits of glaciation is generally much more uneven than in the glaciated tracts, and that flat areas such as would hold the silt in its full thickness are comparatively rare. The silt is seldom preserved in the Ohio Valley, the exposure at Parkersburg being the most conspicuous instance noted. In the northern part of the city it covers an island-like hill which stands about 175 feet above the river, and it there has a thickness of 12 to 15 feet and a porous texture similar to the loess along the valleys farther west.

In the abandoned valley of the Kanawha, leading from St. Albans, W. Va., to Huntington, known as Teays Valley, there is apparently a thin bed of the silt under discussion, capping a thick deposit of silt of different color. The thickness is only 5 or 6 feet, or but little greater than on the bordering uplands.

The deposits in the Beaver and Monongahela valleys which are conjectured to be of this age are only a few feet in depth, those on the Beaver being 5 or 6 feet and those on the Monongahela but little thicker.

CHARACTERISTICS.

Color.—The color of the silt is a distinguishing characteristic, for it is in striking contrast with both the underlying till and with the residuary clay, and is remarkably uniform throughout its extent in this region. It is generally of a pale yellow or ashy color from top to bottom, the soil as well as the subsoil being pale and light colored. For this reason it is widely known as "white clay." In parts of southern Ohio and southeastern Indiana this deposit has given rise to a black soil. This is found mainly in exceptionally flat portions of the uplands, and does not prevail very extensively there, the level tracts being usually characterized by a very light-colored soil.

Texture.—The name silt indicates that this deposit is of fine texture. Ordinarily it contains no grains or rock fragments sufficiently coarse to be detected by the naked eye, but in a few places occasional small pebbles have been noted in it, usually near the bottom of the deposit. The rarity of these pebbles raises the suspicion that they may not be normal to the

deposit. In some cases they may have been brought up from the underlying till by burrowing animals long after the silt was laid down; but in other cases they seem to have been brought in during the process of deposition. A few were found in the unglaciated parts of southeastern Ohio, where their presence seems difficult to explain unless they were laid down with the silt. The pebbles are generally of quartz, though a few other very resistant rocks are represented; this is true of pebbles in both the glaciated and the unglaciated tracts.

Chemical constitution.—But one analysis of this silt has been reported. This first appeared in the Geology of Ohio,[1] and was made by T. G. Wormley, State chemist. The specimen was obtained on the level upland in western Highland County.

Analysis of white clay from western Highland County, Ohio.

	Per cent.
Water combined	5.54
Silicic acid	62.60
Alumina	18.90
Sesquioxide of iron	6.30
Manganese	0.20
Phosphate of lime	0.63
Carbonate of lime	1.89
Carbonate of magnesia	1.82
Potash and Soda	2.32
Total	100.10

Mineralogical constitution.—Two samples collected by the writer have been examined microscopically by R. D. Salisbury. One is from Beech Flats, in northwestern Pike County, Ohio; the other is from western Highland County, not far from the locality from which the sample subjected to chemical analysis was obtained. One is very near the glacial boundary, the other 15 or 20 miles back from the boundary. No essential difference was found in the samples. Both consist mainly of quartz grains, among which are feldspar fragments, hornblende, and possibly epidote and augite; there are also coarse grains of chert and minute concretions of iron oxide. The material is largely angular, even when the grains are of sufficient coarseness to have been liable to become rounded under favorable conditions.

PROBABLE IOWAN AGE.

Standing, as it does, above the Sangamon weathered zone and below the Wisconsin drift, the position of the silt is similar to that of the Iowan drift.

[1] Vol. I, p. 445.

It is certain that the loess on the south border of the Iowan drift in eastern Iowa and western Illinois is of the same age as that drift, for the two deposits connect completely at their borders. The loess sets in abruptly at the south border of the Iowan drift like an outwash from the Iowan ice sheet. The silt appears to hold the same stratigraphic position throughout its entire extent, and no reason has been found for excluding any part of it from the Iowan stage. It is not certain, and perhaps it is scarcely probable, that the deposit is everywhere an outwash from the Iowan ice sheet. But it seems to have been deposited at a single epoch of general low altitude and slack drainage. Its wide distribution on the uplands may, however, be due immediately to the agency of winds.

MODE OF DEPOSITION.

The mode of deposition of the loess and associated silts has been and still remains one of the most puzzling problems of Pleistocene geology. At present little more can be done than to state the several hypotheses and discuss the difficulties of interpretation. This has been attempted by the writer in Monograph XXXVIII of this Survey, and but little can be added to that discussion. The leading hypotheses are known as the aqueous and the eolian. But as a portion of the deposit in southeastern Ohio has been attributed to organic agencies,[1] that interpretation also should be considered.

It is generally recognized that difficulties attend the application of any one hypothesis to the entire deposit. Probably no one questions the view that the influence of the wind has been important, and nearly all will concede that water, or at least imperfect drainage, has been influential. The division of opinion, therefore, is concerned with the relative importance of wind and water in the distribution of the loess.

The question of the influence of the atmosphere as an agent of erosion, transportation, and sedimentation has been carefully examined and ably discussed by Udden, with the result of showing that it is competent to perform as much work as is required in producing this deposit.[2] Chamberlin has recently discussed the peculiarities of distribution and considered the

[1] See Edward Orton: Geology of Ohio, Vol. I, 1873, p. 445; also G. F. Wright: Bull. U. S. Geol. Survey No. 58, 1890, p. 104.

[2] The main results of Udden's investigations are presented in the following papers: Erosion, transportation, and sedimentation performed by the atmosphere: Jour. Geol., Vol. II, 1894, pp. 318-331; Loess as a land deposit: Bull. Geol. Soc. America, Vol. IX, 1897, pp. 6-9; The mechanical composition of wind deposits: Augustana Library Publications, No. 1, 1898, Lutheran Augustana Book Concern, Rock Island, Ill.

difficulties attending the application of either hypothesis to the entire deposit.[1]

The adherents of the eolian hypothesis generally assume that drainage conditions were such that the dust accumulation exceeded the erosion of the land, but they object to the view that much of the surface was under water. The restriction of the deposit to a certain stage in the Glacial epoch is thought to affect in no way the applicability of this hypothesis so long as it is granted that there were exceptionally poor drainage conditions, it being thought that erosion is ordinarily more than a match for dust accumulations. They cite the presence of shells of land mollusks and the wide vertical distribution of the loess as fatal to the aqueous hypothesis.

The adherents of the aqueous hypothesis, while recognizing the difficulties of accounting for the land mollusks and the wide vertical distribution of loess, have emphasized the important fact that the thickest and most porous loess is distributed along the main valleys, and they maintain that its distribution was largely dependent upon the great streams of the region. They also have emphasized the occurrence of coarse material in places in the basal portion of the loess, and the occasional development of distinct beds of silt and also of sand that seem to be water laid.

The close connection between the Iowan drift sheet and the loess deposits of eastern Iowa and western Illinois is recognized by the advocates of each hypothesis, and there seems to be unanimity of opinion that water was an important distributer there, though some difference of opinion exists as to the extent of its influence.

In the region under discussion the variations in level are such as to put the aqueous hypothesis to severe test, for the silt deposits occur from an altitude 500 feet or less above tide up to more than 1,000 feet. In southeastern Indiana this wide range is found within a space of but a few miles. The uplands ordinarily stand 200 feet or more above the surface of the drift accumulations in the main valleys, and nearly 400 feet above the main streams. To submerge this region it would seem necessary to assume a depression that would bring the uplands about to sea level and carry the valleys to a level far below tide, there being no apparent basis for the hypothesis of land barriers or other obstructions which could have held a wide body of water much above sea level.

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[1] Supplementary hypothesis respecting the origin of the loess of the Mississippi Valley: Jour. Geol., Vol. V, 1897, pp. 795–802.

That this region had an unfavorable altitude for drainage in the preceding Sangamon interglacial stage, and probably stood much lower than at present, seems evident from the shallowness of the valleys which were opened on the surface of the Illinoian drift. The drainage conditions seem to have become still more unfavorable during the silt deposition, so that erosion was either suspended or became so weak that it could not keep pace with deposition. This increased imperfection of drainage conditions seems best explained by a depression of the land. This being granted, there may be found but little occasion for dispute between the advocates of the eolian and the aqueous hypotheses, it being only necessary to decide whether or not depression stopped short of submergence. The pebbles and occasional sandy beds found in parts of this silt may help in deciding this question.

The source of the material is a question of prime importance, but so far as the region under discussion is concerned it is largely undetermined. The part which covers the glacial drift seems from the examinations made by Salisbury to have been derived to some extent from glacial deposits, there being minerals present which abound in these deposits and are not present in neighboring rock formations; but the quartz which forms the great body of the silt may easily have been derived from various rock formations, near or remote, east, south, or west from the glaciated districts, and also from the drift.

It remains to consider the influence of organic agencies, the view having been presented by Orton that the white clay of southwestern Ohio is merely the fine material brought up by burrowing animals, earthworms, etc., from the underlying till. This view was suggested before the relationship to the loess had been determined and before the underlying Sangamon weathered zone had been clearly recognized. While therefore the effectiveness of such agencies to produce deposits of considerable bulk is not questioned, the reference of this silt deposit to such agencies can scarcely be sustained. The disturbance produced by these organic agencies has not been sufficiently deep to greatly affect the buried Sangamon soil and weathered zone, there being, as indicated above, a clearly marked line separating the weathered surface of the Illinoian till sheet from the overlying silt. The inadequacy of organic agencies to account for the surface silt becomes still more apparent when the great bulk of the silt farther west is considered, the thickness of the loess in parts of the Mississippi Valley being over 100 feet.

CHAPTER IX.

THE PEORIAN OR POST-LOESSIAL SOIL AND WEATHERED ZONE (TORONTO FORMATION?).

The soil and weathered zone formed on the Iowan till and the loess and associated silts before the culmination of the Wisconsin stage of glaciation have been called the Peorian,[1] because of good exposures in the vicinity of Peoria, Ill, beneath the Shelbyville or earliest sheet of the Wisconsin series. The interval between the Iowan and Wisconsin stages had previously been provisionally named Toronto by Chamberlin,[2] because of excellent exposures of interglacial fossiliferous beds along the Don Valley in Toronto, Ontario, which were at first thought to be of this age. Chamberlin remarks, in connection with the introduction of this name, that the grounds for the correlation are not very strong, and that further investigation may show them to be erroneous. In view of the uncertainty attached to this correlation it has seemed advisable to employ for the present a substitutional name which is known to be applicable to the interval between the Iowan and the early Wisconsin. In case the correlation suggested by Chamberlin is demonstrated to be correct the name Toronto has precedence.

The evidence of this interglacial interval is found not only in the formation of a soil and leached horizon at the top of the loess, but also in a great change in the outline of the ice sheet in the succeeding or Wisconsin glaciation from that displayed in the preceding or Iowan glaciation. There was also a marked change in the attitude of the land, the conditions for drainage being decidedly better in the Wisconsin than in the Iowan stage of glaciation.

These several lines of evidence are well shown in the region covered by the Illinois glacial lobe, and are discussed in Monograph XXXVIII.

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[1] The Peorian soil and weathered zone (Toronto formation?), by Frank Leverett: Jour. Geol., Vol. VI, 1898, pp. 244–249; see also Mon. U. S. Geol. Survey, Vol. XXXVIII, 1899, pp. 185–190.

[2] Classification of American glacial deposits, by T. C. Chamberlin: Jour. Geol., Vol. III, 1895, pp. 270–277.

In the region under discussion the Iowan drift has not been found outside the Wisconsin, and nothing is known concerning the outline of the Iowan drift border. The other lines of evidence are, however, about as clearly shown in this region as in that covered by the Illinois glacial lobe. A comparison of the weathering and erosion on the silt with that on the earliest moraine and drift sheet of the Wisconsin series shows a perceptibly greater change in the silt than has been effected in the surface of the Wisconsin drift; but here, as in the Illinois lobe, the interval appears less prolonged than the Sangamon interglacial stage.

It was remarked in Monograph XXXVIII, in the discussion of this interval, that the weathering appears to indicate that it is comparatively brief, but that the change in the outline of the ice sheet and in the attitude of the land may call for more time between the Iowan and Wisconsin stages of glaciation than the weathering seems to require. It should also be remembered that the Toronto formation has furnished decisive evidence of a prolonged interglacial interval.[1] Should it be proved to represent the interval between the Iowan and Wisconsin deposits its testimony should outweigh any inferences of a brief interval drawn from a comparison of the weathering of the two deposits.

[1] See descriptions by Dr. A. P. Coleman and Prof. D. P. Penhallow: Am. Geologist, Vol. XIII, 1894, pp. 85–95; see also additional interpretation by Dr. Coleman: Jour. Geol., Vol. III, pp. 274, 622–645.

CHAPTER X.

THE EARLY WISCONSIN DRIFT.

GENERAL STATEMENT.

In the Wisconsin stage of glaciation there were several glacial lobes occupying the basins now covered by the Great Lakes and extending beyond them into the lowlands that are connected with the southern borders of the lake basins. These lobes were brought to notice and named by Chamberlin.[1] Those included in the region under discussion are the Miami, Scioto, and Grand River lobes, named from the drainage basins in which they were situated, and their successor, the Maumee-Erie lobe, which occupied the Maumee and Lake Erie basins. The East White lobe is not included, since it falls naturally into a report, now in preparation, which covers the Wisconsin drift of central and northern Indiana and the southern peninsula of Michigan.

Although the several glacial lobes form somewhat distinct areas they are discussed together, each morainic belt being traced so far as possible through the several lobes. The lake history, although closely interwoven with the withdrawal of the Maumee-Erie lobe, is taken up after the discussion of the moraines of that lobe.

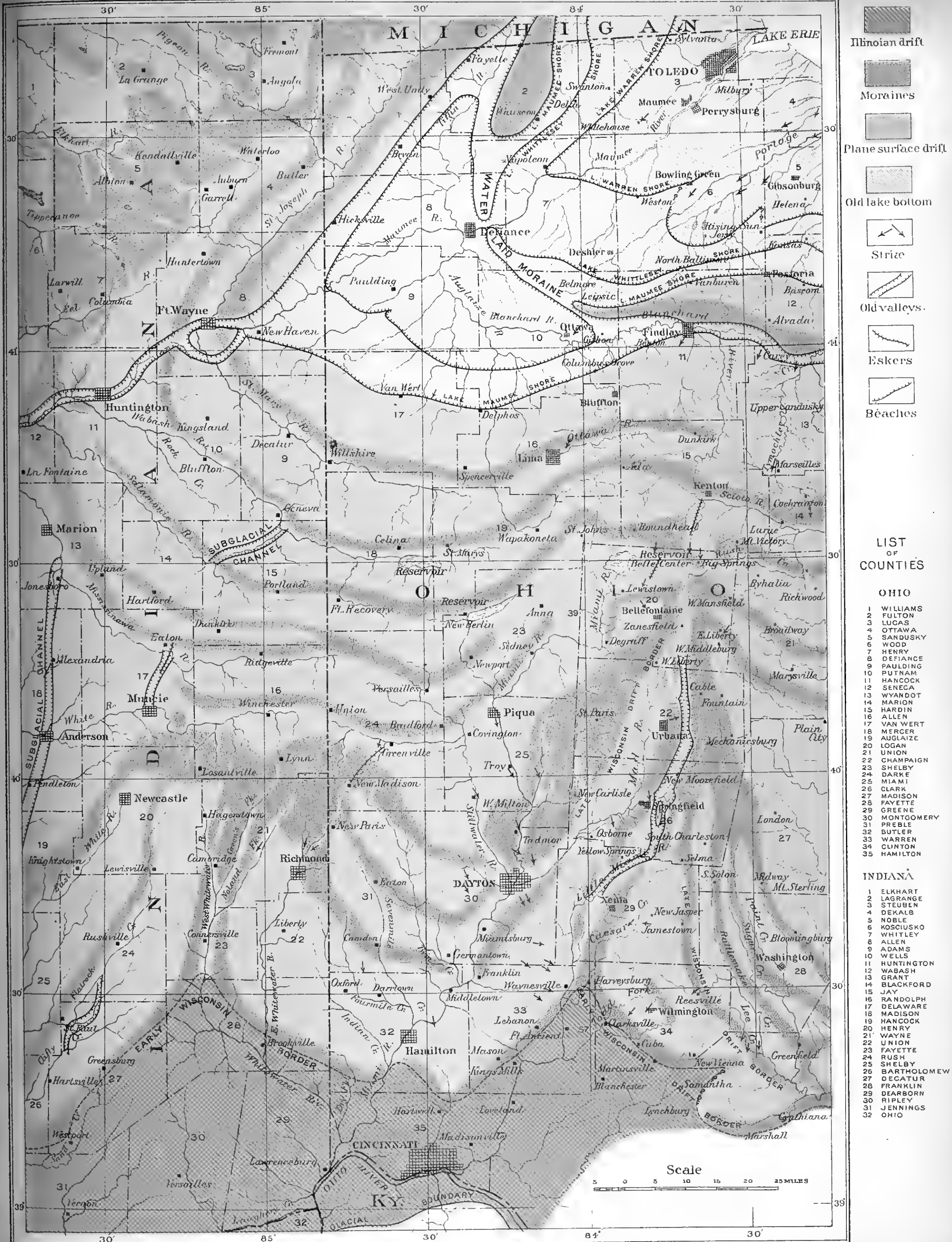
SECTION I. EARLY WISCONSIN DRIFT OF THE MIAMI LOBE.

THE OUTER OR HARTWELL MORAINE.

DISTRIBUTION.

The Hartwell moraine receives its name from the village of Hartwell, Ohio, which stands at the extreme end of the morainic loop, in Mill Creek Valley, a few miles north of Cincinnati. The general course of the moraine may be seen by reference to Pl. XI. From Hartwell it leads northeastward, leaving Mill Creek Valley at Sharonville, and rising to elevated land

[1] Preliminary report on the terminal moraine of the second Glacial epoch, by T. C. Chamberlin: Third Ann. Rept. U. S. Geol. Survey, 1883, pp. 291–402.



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MAP OF THE MAUMEE-MIAMI GLACIAL LOBE

BY

BY FRANK LEVERETT

near Pisgah. From Pisgah it passes down into Turtle Creek Valley just above its junction with the Little Miami Valley near Kings Mills. It then crosses a high tract south of Lebanon and comes to the Little Miami Valley below Waynesville. Near this village it connects with the outer or Cuba moraine of the Scioto lobe.

From the junction of the Hartwell with the Cuba moraine there extends northward along the borders of the Little Miami Valley, across Greene County, a system of morainic ridges which may constitute an interlobate belt of the same age as the moraine. Farther north, in Champaign and Clark counties (see Pl. II), there are drift ridges which are perhaps of more recent date than this moraine, yet older than the outer moraine of the late Wisconsin series. They accordingly seem referable to the early Wisconsin drift, and are discussed in connection with the Hartwell moraine. They lie mainly east of Mad River, and occupy a belt extending from that river eastward several miles. At the north, near the border of Champaign and Logan counties, they are overridden by a moraine of late Wisconsin age.

The moraine curves abruptly northwestward from Hartwell, and follows the southwest border of the Mill Creek lowland tract to the Great Miami River below Hamilton, there being a series of low knolls and ridges of drift along this route, while the uplands to the south have a plane-surfaced drift, probably Illinoian, and a coating of loess-like silt.

In the Great Miami Valley fresh-looking drift and sharply morainic features appear near New Baltimore (Sater post-office), and a belt of morainic type leads westward from there to New Haven (Preston post-office). There are feeble morainic features between New Haven and Philanthropy, but the prominent hills and large valleys of preglacial age are so much larger that the morainic swells are rendered inconspicuous by the contrast. The drift in eastern Hamilton and southwestern Butler counties failed to fill the valleys or even to modify greatly the preglacial drainage, though there is much more drift and the knolls are sharper in the valleys than on the uplands. The moraine enters Indiana near Philanthropy (Scipio post-office), having conspicuous features just south of the village. Its course in Franklin County, Ind., is northwestward through Mount Carmel to East Whitewater River, which it crosses north of Brookville just above its mouth. The moraine here swings toward the north, following the west side of the river into Fayette County and widening near the latitude of Connersville to cover

nearly the whole tract between the two Whitewater rivers. From Connersville northward it is closely associated with the outer moraine of the East White River lobe, and the combined moraines occupy the western half of Wayne County. In northern Wayne County these moraines are overridden by a later one and their northward continuation is completely concealed. It is scarcely probable, however, that they extended farther north than the summit of the highland tract in Wayne and Randolph counties, for it seems natural that the Miami and East White River lobes would have completely coalesced in the low country to the north of these highlands.

Wayne County presents features to which it is necessary to direct especial attention, otherwise there may be a misunderstanding of the interpretation concerning the course of the moraine. The western part of the county is traversed by a series of large ridges and broad valleys, trending north-northeast to south-southwest, the height of the ridges being 75 to 125 feet and their breadth several miles, while the valleys present a usual breadth of about one mile. The drift, as a rule, has considerable depth, both on the ridges and in the valleys. On the ridges or uplands the wells indicate that the rock surface is generally as low as in the valleys, and so far as collected, the evidence all favors the view that the relief of the ridges is due rather to drift accumulation than to rock substrata.

But it is scarcely probable that it was the last ice invasion which determined the main outlines. The course of the moraine under discussion is such as to carry it into the valleys as well as over the ridges of the western part of Wayne County, yet it scarcely touches either a large ridge in the east-central part that lies between East Fork and Nolands Fork, or the uplands west of the West Fork of Whitewater River. There seems little doubt, therefore, that these reliefs are referable to pre-Wisconsin agencies. This determination raises the double question, whether the earlier ice invasion produced the succession of ridges and valleys here displayed or whether it produced a plane-surfaced deposit which was carved into ridges and valleys by the streams which drained this district in the Sangamon or the Peorian or both of these interglacial stages preceding the Wisconsin glaciation. The contours of these ridges and valleys apparently support the view that the drift surface as left by the ice was nearly plane, and that a large amount of sculpturing was accomplished in the interglacial stages just mentioned.

RELIEF.

The highest points along the crest attain an altitude of perhaps 50 feet, while the sags and lower parts of the moraine stand but 10 to 20 feet above the outer border district. The average relief is estimated to be about 30 feet. On the inner border it is even less, there being a sheet of drift connected with the moraine which reduces its relief on that border to but 10 to 20 feet.

RANGE IN ALTITUDE.

The range in altitude depends largely upon the differences in the level of the underlying surface. The effect of the drift accumulation has been to reduce rather than to increase the inequalities of surface, many of the preglacial valleys being deeply filled with drift while the neighboring ridges are thinly coated by it. For example: In Mill Creek Valley, at Lockland, where the moraine has almost its lowest altitude, the entire drift, older and newer, has a depth of about 180 feet below the level of the creek; but on the upland ridges its depth is seldom over 50 feet and often is so slight that shallow wells and cisterns reach the rock. However, in Fayette, Wayne, and Randolph counties, Indiana, there is (including the earlier or Illinoian drift) 100 feet or more of drift on the uplands.

The following table indicates approximately the range in altitude, though possibly portions of the uplands contain higher points than appear in the table. It includes altitudes along ridges in the reentrants between the lobes:

Altitudes along the outer moraine of the Miami lobe.

	Feet above tide.
Highlands in Logan County, Ohio	1,200–1,500
Near West Liberty, on uplands	1,200–1,300
Near West Liberty, in Mad River Valley	1,100
East of Urbana, on uplands	1,050–1,100
Springfield, on moraine, near Standpipe, about	1,075
West of Yellowsprings	1,000–1,025
West of Xenia	940–975
In Spring Valley	760–825
East of Waynesville	875–900
South of Lebanon	875–900
Northwest of Deerfield, in Turtle Creek Valley	675–725
Miltomson and vicinity	900–925
Pisgah (highest point in village) about	960
Mill Creek Valley, between Sharonville and Hartwell	570–600
Between Mill Creek and Great Miami River, about	750
Lowland tract southwest of Venice, about	600

	Feet above tide.
Mount Carmel, Ind., about	1,020
Summit on Brookville and Connersville Pike, near tollgate, 4 miles from Brookville (barometric)	1,050
Alguina, about	1,025
Whitewater Valley at Connersville	850
Harveys station (in valley of Martindale Fork)	958
Morainic hills east of Harveys	1,065
Highlands of northern Wayne and southern Randolph counties	1,200–1,250

The range in altitude between Mill Creek Valley and the highlands of Logan County is, therefore, nearly 1,000 feet. The range in the altitude of the rock surface slightly exceeds 1,000 feet, the altitude being less than 400 feet in Mill Creek Valley, and fully 1,400 feet in Logan County, near Bellefontaine.

TOPOGRAPHY.

The moraine has, as a rule, a gently undulating surface, but as its features vary from place to place a detailed description will be given, beginning in southern Logan County, Ohio, where moraines of early Wisconsin age first come into view outside the later ones, the moraine is carried thence south and west

Sharp ridges with north-south trend, separated by narrow gravel plains, appear in southern Logan and northern Champaign counties. There are two of these ridges in southern Logan County, and a third one sets in in northern Champaign County, which at its northern end lies west of the others, but which, owing to the disappearance of the other ridges, becomes within 2 to 3 miles to the south the outermost and main ridge. These ridges are of variable height and stand 20 to 100 feet above the bordering gravel plains. Farther south, in the vicinity of Kings Creek, the ridging becomes less sharp and the moraine consists mainly of low knolls 10 to 25 feet high, though it includes occasional larger ones 50 to 75 feet in height. From Kings Creek southward to Springfield it is spread out over a breadth of about 3 miles, while north from that creek the united breadth of the ridges would scarcely amount to 2 miles. With increase of breadth there comes a softening of contour, and much of this portion of the moraine consists of swells only 10 to 20 feet high, among which are numerous shallow basins. Near the eastern border of the moraine, and apparently connected with a gravel plain lying outside (east) of it, there are irregular sags and depressions, formed perhaps by the escape of water from beneath the ice sheet. In the midst of the gravel plain there are occasional drift

knolls rising, in some instances, 40 to 50 feet above the surface. Whether they are the product of this lobe or of the Scioto lobe was not determined.

Within the city of Springfield morainic features are developed, a well-defined ridge passing the standpipe and thence southwestward through the southeastern part of the city. There is a distinct ridging in a northeast-southwest direction, and along the crests and slopes are knolls 15 to 30 feet in height. The moraine loses much of its strength in the southern part of Springfield Township, though numerous gravel knolls extend toward Selma. From Springfield Township southwestward to the Little Miami River there is a gently undulating till tract, dotted with occasional gravelly knolls, but not a well-defined moraine. A conspicuous group of knolls occurs near the county line about 2 miles northwest of Yellow Springs, the most prominent knoll (Polhemus Hill) standing nearly 75 feet above the bordering country. This knoll is elliptical, with a northwest-southeast direction, having a length of about one-fourth and a width of one-eighth mile. Other knolls in its vicinity are 15 to 25 feet in height and of sharp contour. Just west of Yellow Springs is an elliptical knoll with north-south trend which rises about 30 feet above the bordering country. It is 40 to 50 rods in length and 20 to 25 rods in width. On the north bluff of Little Miami River, near the line of Beaver Creek and Xenia townships, there is a prominent knoll at least 75 feet in height. Toward the west, between this hill and Beaver Creek Valley, the undulations are sharper than to the north and the topography again appears morainic. Sharp gravelly knolls and ridges 15 to 30 feet high are common, and occasionally an esker-like linear gravel ridge is found among the knolls; till swells with gentle slopes also occur. North of Xenia, between Wilberforce and the Little Miami River, there are several other sharp gravelly knolls 20 to 50 feet high. East and south from Xenia for several miles there is only a gently undulating till tract. West of Xenia, at the west side of a gravel plain known locally as "Cherry Bottoms," several prominent knolls form a group about one-half mile long from north to south and one-fourth mile from east to west. The highest points are 50 to 60 feet above the plain. Knolls are numerous south and west from this group, but they are only 10 to 20 feet high. East, south, and north from Spring Valley the drift on the uplands consists of gravelly or sandy knolls and ridges 20 to 25 feet in height which wind and interlock in morainic fashion. This seems to be an interlobate tract of the same age

as the Hartwell moraine. It is probable that for 5 or 6 miles south from Spring Valley the Miami portion of the interlobate moraine lies between Cæsars Creek and the Little Miami River, while the Scioto portion lies east of the creek, the position of the creek being determined to some degree by this relation to the ice lobes.

East and south of Lebanon low swells occur on the slopes of the preglacial ridges and in valleys or lowland tracts, but the moraine is rather inconspicuous. It is strikingly in contrast with the neighboring portion in Turtle Creek Valley, which for about 3 miles above the mouth of the creek has so many sharp swells and gravel knolls that the valley is nearly filled. The highest are but 40 to 50 feet, and many are only 15 to 20 feet in height, but they are closely aggregated and constitute a noticeable feature. They have forms independent of the drainage, present or past, and connect here and there in the irregular and peculiar manner common to moraines.

About 3 miles above the mouth of Turtle Creek the valley becomes free from knolls and contains a broad, swampy lowland plain about a mile in width. This plain passes northwest into the Great Miami drainage basin, the lower course of Dicks Creek, a tributary of the Great Miami, lying in it. The freedom from knolls gives this portion of the valley or lowland strong contrast with the portion occupied by the moraine. This lowland tract, which was first discussed by Orton in a report of the Ohio geological survey,[1] appears to be a line of preglacial drainage, as noted in Chapter III.

On the upland tract between the Little Miami River and Mill Creek, in southwestern Warren, southeastern Butler, and northern Hamilton counties, no very prominent knolls were observed, but the surface has many swells with gentle slope, and the drift is sufficiently heavy to greatly mask the preglacial valleys and ridges. In the vicinity of Pisgah the drift has unusual thickness as well as altitude, and there are knolls of morainic type 10 to 20 feet in height. They cover but an acre or two each. Such drift knolls continue down the slope into Mill Creek Valley at Sharonville. West of Pisgah, in the vicinity of Westchester, there are some larger drift knolls. One just west of the Cleveland, Columbus, Cincinnati and St. Louis Railway and north of the Westchester and Pisgah wagon road is 60 feet or more in height. It is in a lowland tract, as are nearly all the other prominent knolls near Westchester.

[1] Geology of Ohio, Vol. III, 1878, pp. 381–382.

Mill Creek Valley between Sharonville and Hartwell contains many morainic swells, the highest of which stand probably 30 feet above the general level of the valley, but the majority only 10 to 15 feet, perhaps less. At Reading the drift surface consists of winding ridges of gravel, 20 feet or more high, but directly west, in Wyoming and Lockland, it consists in the main of conical swells of till 10 to 30 feet high, but few of which are abrupt or sufficiently prominent to be worthy of notice. Notwithstanding their inconspicuousness when contrasted with the bluffs and hills bordering Mill Creek Valley, these knolls constitute a marked feature when Mill Creek Valley alone is taken into account. South of Hartwell and also north of Sharonville the valley has a smooth plain from bluff to bluff, aside from some low hills southeast of Glendale, which have a rock nucleus. Much of it above Sharonville is a marshy tract so level that it has been difficult to drain, and a portion of it has been converted into ice ponds. South of Sharonville, where the moraine appears, the valley bottom is undulatory, affording beautiful sites for the Cincinnati suburbs from Wyoming to Hartwell. South of Hartwell the valley is again free from drift knolls, and continues so to its mouth at Cincinnati. The knolls between Hartwell and Sharonville, like those in Turtle Creek Valley, appear to be in no way dependent upon the present drainage for their form, but, like morainic swells on the uplands, they present a topography readily distinguishable from the drainage erosion type.

The drift west of the Great Miami, between New Baltimore and Venice (in the lowland tract mapped by Orton as an old valley),[1] has a swell-and-sag till topography. The undulations are slight, seldom reaching a height of 20 feet. The surface is bowlder strewn, and is not coated by a sheet of silt such as occurs farther south and west. A short distance southwest of New Haven (Preston post-office) the hills set in, and again it is difficult to distinguish a morainic belt, though knolls occur on the lowlands. It may be remarked in passing that drift knolls are not often seen in the lowlands south of this moraine, either in Ohio or in Indiana. South of Philanthropy, near the State line of Ohio and Indiana and on the west side of Dry Fork, is the most prominent drift aggregation in this part of the morainic belt. It consists of a ridge of gravel, 500 yards or more in length and about 200 yards in width, trending northeast to southwest and standing 30 to 50 feet

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[1] Geology of Ohio, Vol. I, 1871, p. 419. Map of Hamilton County.

above the surrounding country. Several small knolls, also gravelly, are connected with it at the sides. Between this prominent knoll and the East Whitewater River there are on the uplands low till swells 5 to 10 feet high, while knolls of gravel 10 to 20 feet high characterize the drift in the valleys and on their slopes. West of East Whitewater, on the uplands immediately north of Brookville and about 3 miles from the city, there are both till and gravel knolls, the largest having a height of about 20 feet. The knolls are in several instances elliptical, but there appears to be no uniformity of trend.

On the inner border plain north from these knolls, in Franklin County, few knolls occur that are as much as 10 feet in height. In southeastern Fayette County the surface is very uneven, there being ridges and dry valleys which are apparently partially masked interglacial drainage features. In various positions in these valleys and on the ridges and slopes, swells 10 to 20 feet high occur, many of which are gravelly. In northeastern Fayette County and in Wayne County there are few knolls that rise to a height of more than 10 to 15 feet, the only prominent exception noted being a group in the vicinity of Doddridges Chapel, Washington Township, Wayne County, whose highest members have a height of 40 to 50 feet. In northern Wayne County abrupt knolls 30 to 40 feet in height are common, but it is probable that these belong to a later morainic belt which crosses northern Wayne and northeastern Henry County in an east-west direction.

STRUCTURE AND THICKNESS OF DRIFT.

The soil of this moraine is strikingly in contrast with that of the tract south of it. It is usually dark colored and loamy, with an admixture of pebbles and sand, while that outside is a light-colored clay or silt with scarcely a trace of sand and pebbles. In the morainic tract there are also bowlders on the surface on upland tracts as well as along streams, but in the outer border district none occur at the surface except along valleys or on slopes where drainage erosion has carried away the silt or surface deposits that had covered them.

Throughout its entire course this moraine consists mainly of till, but is characterized by occasional gravelly knolls among the till swells. The gravel knolls are especially frequent where the moraine crosses valleys, being present in nearly every good-sized valley within the morainic belt,

but they occur also on the uplands. A good illustration of such knolls in the latter situation may be found on the elevated tract north of Brookville, Ind., at an altitude 400 feet above the Whitewater Valley. Here two gravel knolls were observed, each about 20 feet in height, standing in the midst of the till swells of the moraine and in no way connected with drainage lines. Having considered the question whether those which occur in the valleys may not have been sculptured into their present forms by postglacial drainage erosion, the writer is convinced that their origin is independent of the present streams. They were neither deposited by them nor are they remnants left by erosion. They usually present the hummocky irregular surface characteristic of morainic deposits. Only the knolls, however, are composed largely of assorted material, the low-lying tracts among them, as shown by well borings, being frequently underlain by till.

We may now pass to a more detailed description of the noteworthy illustrations of drift structure and thickness. The discussion begins with the tract in the Scioto-Miami reentrant angle.

At West Liberty, Ohio, in the valley of Mad River, a gas well penetrated 216 feet of drift, largely sand and gravel, while in the same valley $1\frac{1}{2}$ miles east there are exposures of limestone along Mackocheek Creek at about the altitude of West Liberty, and ledges still farther east rise to a height of 100 feet above the village, or 1,200 feet above tide. Wells are often obtained at 25 to 50 feet on the morainic ridges, after penetrating a stony till.

Several deep wells have been made in the vicinity of Urbana, of which the following tabulated records were furnished by T. F. Moses, formerly of that city:

Table of wells near Urbana.

Name.	Altitude above tide.	Depth of drift.
	Feet.	*Feet.*
Tannery well	1,044	150
Power well	1,001	133
Glue factory well	1,020	102
Sycamore well	1,000	150
Citizens, No. 1	1,061	150

Dr. Moses furnished the following section of the drift in the tannery well, but of the others no record of drift structure was kept:

Section of drift in the tannery well at Urbana.

	Feet.
Soil, subsoil, etc	10
Gravel and sand	35
Blue clay (pebbly)	25
Sand and coarse gravel	10
Fine gray clay	35
Coarse gravel mixed with clay	15
Blue bowlder clay	25
Depth to limestone	150

At present there appears to be no means of determining how much of the above section is referable to the Wisconsin drift. Four miles north of Urbana, on the north side of Kings Creek and on the moraine, is a well on George Creffield's farm which penetrated 103 feet of till and obtained water from a gravel bed at the bottom. At a farm house 40 rods east of Creffield's is a well 93 feet deep which did not reach rock.

In the southern part of Urbana, near the waterworks and west of the Erie Railway, a gravel pit is opened in a knoll to a depth of about 30 feet. It has deposits of till at the top and the south end, but the body of the knoll consists of gravel and cobble in which large limestone slabs are included. The stones are nearly all limestone, the Archean rocks constituting scarcely 1 per cent. A few fragments of shale were observed which appear to have been derived from Devonian strata.

The sections just given from the vicinity of Urbana represent no more variety than is commonly displayed in the wells and exposures in this district. In the northern part of Springfield are several good exposures of the drift structure which are found to show both till and gravel in a single knoll. The most extensive one is on the north side of Buck Creek, just east of the Cincinnati, Sandusky and Cleveland Railway. Its length is 100 to 125 yards and its depth 15 to 25 feet. The western half is composed of yellow till, exposed to a depth of 15 feet, containing a few thin layers of sand horizontally bedded. The eastern half shows a curious alternation of assorted and unassorted material. The bedding, so far as traceable, is mainly horizontal, but near the top are beds which have a dip of 20° to 30°. In the portions where bedding is not distinct there is a mixture of flinty material of all sizes from small pebbles up to bowlders 3 feet in diameter.

A well boring in Buck Creek Valley west of Market street, Springfield, penetrated about 100 feet of cobble and gravel before striking rock. This seems remarkable, since the valley here is not more than 100 yards in width, and has rock bluffs on either side, the height of the bluffs being about 130 feet above the rock floor. A plain, on which there is some cobble and coarse gravel and an occasional large bowlder, borders this rock-bound channel on the south. South of this plain, at an altitude perhaps 20 feet higher and near the railroad stations and post-office, there was originally much boggy land with peat underlain by sand. South of the railroad stations, on a terrace-like plain 25 to 30 feet higher, there is gravel, but a line of springs issuing near the base of this bench indicates an impervious substratum, probably clay, at that level. South from the plain just described is an undulating tract unmodified by fluvial action. The bench last mentioned apparently represents the highest terrace and stands about 75 feet above Buck Creek. North of Buck Creek the uplands in the city of Springfield rise to a height of 75 to 100 feet, and, as stated above, contain till as well as assorted material. The lower plain which borders the immediate bluffs of Buck Creek was apparently occupied by a stream leading westward after the Miami lobe had withdrawn. The relationship of the upper plain to the glacial deposits is not determined.

The abandoned or concealed valley 3 miles west of Springfield, to which Orton has called attention,[1] lies west of Mad River Valley in a nearly plane tract. The old valley led directly across the neck of land around which the river now flows. It was so completely filled with drift that no suspicion of its existence was aroused during a railway survey across it, and it was discovered in the attempt made by the railway company to tunnel it. It was then found that the drift along this line extends at least to the level of Mad River. The deep cutting made by the railway exposes an interesting but complex section, there being two alternations of yellow and blue tills. At the top is a yellow till 10 to 12 feet thick which follows the arching surface of the ridge, beneath which is a bed of blue till 2 to 10 feet thick, its thickness being greatest under the crest of the ridge. Under this is a bed of yellow till about 6 feet in thickness, which extends both east and west beyond the limits of the blue till, and there immediately underlies the upper bed of yellow till. Beneath this bed is the main deposit

[1] Geology of Ohio, Vol. I, pp. 460–461.

of blue till, which is here exposed to a depth of 35 feet without reaching its base. In the blue till are thin horizontal beds of sand of slight extent. Near the western end of the same railway cutting and toward the top of the bank there is a slight exposure of beds of gravel which are disturbed and shoved into a nearly vertical position. The blue till beneath these beds is also disturbed to a slight depth, as if by a vigorous shove from the west. This disturbance of the beds is readily attributable to the movement of the ice sheet across them. It is probable, though as yet scarcely demonstrable, that the Wisconsin drift includes only the upper yellow and blue till sheets.

About 3 miles north of Xenia, on the south bluff of the Little Miami River, is a sharp drift knoll about 40 feet in height, which has been opened from top to bottom; indeed, the excavation goes about 15 feet below the base of the knoll. The knoll is made up almost entirely of gravel, and this gravel, especially in the central and southern parts, has a decided southward dip of 20° to 30° or more. At the level of the base of the knoll the gravel suddenly ceases and below it there is a level-topped yellow till with weathered and leached surface, which appears to be a buried soil or old land surface upon which the knoll was deposited. The gravel being Wisconsin, the till and underlying deposits are referred with some confidence to pre-Wisconsin time. The till has a thickness of about 10 feet. Beneath it are sand and gravel beds in arching and oblique attitudes. A chain of knolls leads westward from this gravel knoll along the north border of the gravel plain locally known as "Cherry Bottoms," and then southward along its west side, constituting the outer border of the moraine, but no other knolls have been opened sufficiently to show their structure.

No records have been obtained of deep wells in Greene and Warren counties, Ohio, except at the Lebanon gas well, where the drift has a thickness of 126 feet. The drift is usually not thick, if we may judge by the altitude of rock outcrops along streams. Probably the average thickness on uplands in these two counties is less than 50 feet.

At the time of a visit to Turtle Creek Valley, in September, 1891, the grading for a new railway was in progress. The grading begins near the point where the moraine touches the Little Miami gravel plain and passes northward, showing the structure of the drift to a depth of several feet. There is a slight capping of silt or earthy deposit on the outer face of the

moraine, which blends with the earthy deposit that caps the gravel plain, but within one-half mile north from the gravel plain the moraine becomes nearly free from silt. The main part of the grading is through ordinary till, which appears to extend to the very border of the gravel plain and down to the same level. A large percentage of the pebbles included in the till are striated. There are but few Canadian rocks present, the majority of pebbles being limestone from the western Ohio region. Knolls in this valley contain some till, but are composed mainly of sand and gravel.

In the moraine west of Kings Mills, on the Little Miami bluff, a well at Mr. Hill's residence has a depth of 60 feet. It is mainly through gravel, an exceptional structure for the upland drift. At Pisgah, in southeastern Butler County, which is probably the most elevated point in this part of the county, the drift has a thickness of 75 feet or more. A buried soil was struck in the schoolhouse well at this village below blue till at a depth of 45 feet. This probably separates the Wisconsin from earlier deposits of drift. A well a short distance east of the village, on land owned by Mrs. Webb, was sunk to a depth of 75 feet without reaching rock. It was thought by citizens of Pisgah that this also struck a black soil, but no witnesses to the fact were interrogated. The information concerning the well at the schoolhouse was given by Mr. Milton Thompson, a farmer living near Miltomson station, who was present when the soil was struck. He described it as black and containing bits of wood. On Thompson's farm the wells are about 40 feet deep, and do not reach rock. The strata penetrated are as follows:

Section of wells on M. Thompson's farm, near Pisgah, Ohio.

	Feet.
Soil and yellow pebbly clay (till)	10–15
Blue till, not very hard	20–30
Sand bed containing water.	

On the east bluff of Mill Creek, east of Sharonville, J. P. T. Miller's well penetrated about 40 feet of cemented gravel, and there are outcrops of cemented gravel in the ravines in that vicinity. It is not improbable that this may belong to the earlier drift sheet, though located in the moraine, since in that vicinity the moraine appears to consist of but a thin sheet of drift.

Records of several deep borings along Mill Creek Valley—that is, the old valley of the Ohio River—are introduced here. Some of these belong to the tract lying north of this moraine. They serve to show how greatly

the glacial drift has softened the outlines of this still rather broken region by filling up its valleys. The list of borings begins at the northern end of Mill Creek Valley, where it joins the Great Miami Valley, and includes a few wells in the latter valley.

At Hamilton a prospect boring for gas penetrated 210 feet of drift, which was nearly all gravel and sand, striking rock at an altitude of about 390 feet above tide, or 42 feet below low water in the Ohio at Cincinnati. A well at Snyder's paper mill, in the eastern part of Hamilton, penetrated a bed of bowlder clay beneath the gravel, as follows:

Section of well at Snyder's paper mill, Hamilton, Ohio.

	Feet.
Gravel	80
Blue bowlder clay	20
Gravel	20
Total	120

A well at the Franklin paper mill in the southern part of Hamilton penetrated a blue, pebbleless clay near the bottom, as shown by the following section:

Section of well at Franklin paper mill, Hamilton, Ohio.

	Feet.
Cobble and gravel	25–30
Fine gravel with some sand	50
Blue clay without pebbles	25
Sand at bottom.	
Depth of well	102

Wells in the Great Miami Valley 5 to 6 miles below Hamilton, near the mouth of Indian Creek, strike a black muck under the gravels of the glacial terrace at a depth of 60 to 65 feet, the altitude at the well mouths being about 40 feet above the river. This black muck probably separates gravel of Wisconsin age from earlier deposits.

The exposures in Mill Creek Valley, from the border of the gravel plain on the Miami River near Hamilton to the border of the moraine near Reading, are quite uniformly till, or deposits such as would be produced by glacial action, and differ markedly from the gravel deposits that follow the Great Miami and Ohio rivers. Three miles southeast from Hamilton, in the lowland tract near the canal, a gardener, Joseph Federlee, made a well 110 feet deep which did not strike rock. The drift consists mainly of a blue,

pebbly clay. This well is scarcely one-fourth mile south of the bluff or upland north of the valley, in which rock rises 100 feet or more above the level of the well mouth. A small gravel knoll directly across the highway from Federlee's residence has been opened and shows calcareous sand and gravel containing many limestone pebbles in arching beds. A mile or more east of this place the Panhandle Railway makes a slight cutting, in which are exposed—

Railway cutting in Mill Creek Valley.

	Feet.
Yellow till	6–8
Horizontally bedded yellow sand	5–6
Blue sandy till at base.	

Such knolls are rare and much of the valley is very level, but these few knolls, taken in connection with the well sections, indicate that there is very little true alluvium in the valley, and that here, as well as farther south in the moraine, the filling is of glacial origin. The deposits are certainly not fluvial.

At a blacksmith shop in Port Union a well 36 feet deep gave the following section:

Section of well at a blacksmith shop in Port Union, Ohio.

	Feet.
Yellow pebbly clay	12
Blue clay	15
Blue-gray sand, caving badly	2–3
Hard, blue, pebbly clay	7–8
Sand and water at bottom.	

In Rialto, at a paper mill beside the canal, only a few rods from the west bluff of Mill Creek Valley, a well over 100 feet deep and several others 90 feet deep did not reach the bottom of the drift. In all of these wells the greater part of the drift is reported to be blue clay, the sand and gravel being interstratified in thin beds. Stones were frequently encountered, making it difficult to drive the wells. In one well they were so numerous at a depth of 90 feet that the boring was abandoned. North of the Rialto station, a few rods east of this paper mill and farther from the bluff, is a cutting 10 feet in depth, which exposes yellow till with blue till at the base. The upper portion of the till, to a depth of 2½ to 3 feet, contains fewer pebbles than that in the lower portion of the exposure. In the till are many small blocks of limestone, such as find outcrop on the borders of the valley, and these are but little waterworn, while many are striated.

A mile or more east of Rialto, near the east side of the valley, is a well about 35 feet deep located on a knoll perhaps 15 feet in height. It passed through assorted material in its upper part, but the lower part penetrated blue pebbly clay.

In Sharonville wells penetrate about 20 feet of till, and at that depth obtain water from gravel. On Mr. Ferris's farm, 1½ miles west of Sharonville, on the west side of the canal, a well penetrated the following beds:

Section of Ferris well near Sharonville, Ohio.

	Feet.
Yellow and blue clay, thought by the well diggers to have contained pebbles (dug)	61
Sand (bored with small auger)	16
Total	77

On J. Brown's farm, 1 mile southeast of Sharonville, wood was encountered in blue till at a depth of 20 to 40 feet. At the gas-well boring in Lockland, in the valley of West Mill Creek, the surface being fully 30 feet lower than the upper lock in Lockland, or about 546 feet above tide, drift was penetrated to a depth of 190 feet, showing the rock floor of the valley to be but 356 feet above tide. This, so far as known to the writer, is the lowest altitude of rock floor yet found in the valley. The exact section was not recorded, but Mr. Latty, of Lockland, who was interested in sinking the well, made the following statement from memory:

Section of drift in a gas boring at Lockland, Ohio.

	Feet.
Alluvium	8
Gravel	12
Blue pebbly clay	22
Alternations of sand, gravel, and blue clay, in beds each but a few feet thick	148
Total drift	190

At Stearns and Foster's cotton mill in Lockland, near the upper lock, a well whose surface is 565 feet above tide is 147 feet in depth, and did not reach rock, but terminated in sand beneath a thick bed of blue clay. At Wyoming the city well (whose mouth stands 600 feet above tide) penetrated 155 feet of drift without reaching rock, there being yellow and blue clay, gravel, and bowlders in the upper 84 feet, and sand in the remaining 71 feet.

A short distance south of Wyoming and Lockland, on the west side of Mill Creek Valley, the Cincinnati, Hamilton and Dayton Railway was, at the time of a visit in October, 1889, making a cutting for a switch between

its main line and a starch factory east of the railway. The cutting passes through a till knoll about 30 feet high. Yellow till covers the knoll like a blanket to a depth of about 12 feet. The till is soft and has no silty covering. Below it is a dark-blue till, also soft, having pebbles very irregularly distributed, being thickly set in places, but in other places nearly free from them. Where pebbles are wanting the material has the appearance of a very fine, laminated, sandy clay. In the deeper part of the cutting some coarser sand of yellowish color is exposed. Large pieces of wood were embedded in the blue till at a depth of 30 feet beneath the highest part of the knoll. The largest piece observed was about a foot in diameter and 3 to 4 feet long. It was very soft and so spongy that a spade could be pushed into it readily. One large piece, several inches in diameter, had a curled grain and an irregular surface and appeared to be a root.

John Bonsall Porter, formerly engineer of the Glendale waterworks, informed the writer that several of the suburbs of Cincinnati have obtained a public water supply by sinking tubular wells in Mill Creek Valley. These wells ordinarily penetrate 75 to 150 feet of blue clay, largely glacial, beneath which is sand and fine gravel, which has been penetrated in some cases 100 feet without entering rock. From this sand, which Porter regards as the deposit of an old river, an unlimited supply of good water is obtained. The wells at the Glendale plant, in the center of Mill Creek Valley, 2 miles from the village, pass through 97 feet of "drift and alluvium," then strike coarse sand of dark color, which in one case was penetrated 78 feet without reaching rock. The altitude at the bottom of the deepest well is only 395 feet above tide, or about 40 feet below the low-water level of the Ohio at Cincinnati. The water stands in the wells at about 560 feet above tide, or practically at the surface. Other villages using wells of this class at the time this communication was received (June, 1895) are Wyoming, Hartwell, Reading, Carthage, St. Bernard, Norwood, Linwood, and Madisonville. The last five lie outside the limits of this moraine. The wells at Norwood reach a depth of 235 feet, but those at other villages fall below 200 feet. Whether the sand found in the lower part of these wells is strictly alluvial and earlier than the glacial deposits, or whether its deposition resulted in some way from the ice invasion, can not perhaps be decided at present.

It may perhaps be difficult to determine how much of the drift in Mill

Creek Valley should be referred to the Wisconsin stage of glaciation. It seems probable, however, that it should be only a small part. It may include only the fresh-looking surface till, such as is exposed in the railway cutting, and may extend but little below the level of the flat part of the valley.

Along the Great Miami River there is a gravel-filled valley three-fourths to $1\frac{1}{2}$ miles in width, of which the upper 60 feet of filling, as noted above, seems referable to the Wisconsin outwash. West of this valley the uplands in Hamilton and Butler counties, Ohio, carry a thin sheet of drift, but the lowlands and larger valleys carry a very thick deposit. The lowland tract connecting the Great Miami with Whitewater River, in northwestern Hamilton County, though utilized probably as a preglacial and possibly an interglacial drainage line, seems not to have been thus used since the Wisconsin ice invasion Like the valley of Mill Creek, it has been filled chiefly with till. A well in this lowland, at Mr. Guest's, about a mile east of Preston post-office, passed through 90 feet of till and, at bottom, 10 feet of sand before obtaining water. The well surface is about 70 feet above the bed of Dry Fork at Preston. Ordinarily wells in this till tract find water at 40 feet or less, there being deposits of water-bearing sand interbedded with the till. The till tract presents a variable surface structure, such as is displayed in the majority of moraines whose main component is till, there being many places where sand and gravel immediately underlie the soil, but these are apparently in local and isolated tracts.

North and northwest from this lowland till tract are uplands standing 200 to 300 feet above it. On these uplands the prominent ridges and hills have a very thin coating of drift, but the lower parts of the uplands are covered with a sheet of till of moderate thickness. The valleys have considerable gravel either flanking their slopes or aggregated in low knolls in their bottoms, but the main bulk of the drift in the valleys is till, the gravel seeming to be mostly superficial. These hills are not silt covered in Butler County, Ohio, but in Franklin County, Ind., there is a narrow belt along the north side of the Whitewater which resembles the tract south of that stream in having a silt 3 to 4 feet or more in thickness covering an old drift, the Wisconsin drift being absent. With the exception of this narrow belt, which seldom reaches back 5 miles from the Whitewater Valley, the surface portion of the drift of northeastern Franklin County is a fresh,

pebbly till dotted with occasional gravel knolls. The drift is about as thin there as in portions of the county outside the limits of the Wisconsin drift. Many wells have struck rock at less than 20 feet. In a trip along the watershed north from Mount Carmel the thickness of the drift was noted at several wells, as follows:

Thickness of drift in wells near Mount Carmel, Ind.

	Feet.
J. A. Applegate's well	8
Mr. Merrill's well	4
George Dixon's well	20
John Schultz's well	13
George Schultz's well	18
Mr. Howe's well (SE. part sec. 21, Bath Tp.)	22
North part of sec. 21 (owner not ascertained)	16

In Howe's well there was—

Section of drift in Howe well.

	Feet.
Till	15
Sand bed	2–3
Clay	3–4
Total	22

At Dixon's a cistern 12 feet deep penetrated several feet of till, then passed through a black soil about 2 feet thick, and entered a whitish clay. No other instance of a buried soil came to the writer's notice in this neighborhood. Although the drift is mainly till, several gravel knolls have been opened in the valleys northwest of Mount Carmel. Southeast of Mount Carmel also, near Philanthropy, there is a large gravel knoll, which is described on a previous page. On the uplands west of the East Whitewater, 2 or 3 miles north of Brookville, there are two gravel knolls, one of which, near the center of sec. 7, T. 9, R. 2 W., contains a gravel pit 20 feet or more in depth. The gravel beds are in arching or oblique positions. The well at a schoolhouse nearby, in the same section, 30 feet deep, was mainly through till and did not strike rock. Several other wells in the neighborhood, 20 to 25 feet deep, do not strike rock; but rock outcrops appear in a ravine east of the gravel pit at a level scarcely 30 feet below its base. The variability of the drift is shown by wells, some of which are mainly through till, while others are in gravel much of their depth. Bowlders are usually abundant in the vicinity of these gravel knolls. The valley of Whitewater River does not contain gravel knolls at the place where the ice sheet overhung it when the moraine was forming. The valley at this point

is now about 400 feet deep, and was perhaps 100 feet deeper previous to the deposition of glacial gravels by streams from the Wisconsin ice margin.

In southern Fayette County, near Everton, morainic features are well displayed and the structure of the drift is variable. Several gravel knolls occur between Everton and Alguina, and also northwest of Everton, but the greater part of the drift is till, both at the surface and in well sections. In northeastern Fayette and southwestern Wayne counties there is but little gravel on the uplands. The soil is not so loose and loamy as is usually the case in morainic belts, and is called by the residents "cold clay." The thickness of drift here is variable. One well near the county line, a mile or more east of Waterloo, is about 80 feet deep, and does not strike rock. About 4 miles southeast of Waterloo and east of the West Whitewater there are rock quarries. Along the West Whitewater in Fayette and Wayne counties there is a gravel plain one-half mile to a mile wide, which has a deep deposit of glacial gravel. The bottom has been reached only in the few gas-well borings that have been made along it. Several borings along this valley, both within the moraine and south of it, that reach rock are discussed below, beginning near the head of the stream at Dalton, Wayne County, on Nettle Creek, one of the main tributaries. At Dalton the thickness of drift in the gas well is 240 feet and the altitude of the well mouth is about 1,100 feet. There was a slight amount of gravel at the surface, but the greater part of the drift was found to be till, mainly of a blue color. Dr. E. H. Thurston, of Hagerstown, gave the following information concerning wells in that village, the altitude of which is about 1,000 feet: Eight gas wells have an average of about 100 feet of drift, the least amount being 78 feet. The upper 50 feet is largely gravel, the remainder till. At Cambridge (whose altitude is about 940 feet) two wells show about 100 feet of drift. One has 10 to 15 feet of gravel at top, the remainder of the drift being blue till. A reliable record of the second well was not obtained. There are outcrops of rock in Whitewater Valley in that vicinity at about the level of the wells. A mile west of Cambridge, and at 70 feet higher altitude, a well penetrated 160 feet of drift; the upper and lower portions of this were sand and gravel, a considerable amount of till intervening. At Dublin, 2 miles west of Cambridge, and at an altitude 115 feet higher, a gas well penetrated 300 feet of drift. At Connersville several deep wells

have been made in prospecting for gas. The first boring, the altitude of which is about 850 feet, penetrated 75 feet of drift, nearly all sand and gravel. No record of the other wells could be obtained.

Between the West and the East Whitewater rivers, in Wayne County, the record of but one well in which the rock is reached was obtained. This well is at Centerville, where a natural-gas boring penetrated 176 feet of drift, mainly till. A little gravel was passed through near the surface. The altitude is about the same as the Centerville station, 995 feet above tide. Water wells in this district often go down about to the level of the bordering valleys without entering rock.

E. R. Quick, of Brookville, has collected the following information concerning the drift in the gas wells in the vicinity of that city. A well at a warehouse east of the river, near the forks of the Whitewater, altitude 630 feet above tide, penetrated 135 feet of drift, all sand and gravel. A well at the Franklin County Infirmary, west of the river, penetrated about 140 feet of sand and gravel and struck rock at about 2 feet higher altitude than at the warehouse. At Mr. Brocker's, in Brookville, west of East Fork, at an altitude also about 630 feet above tide, a well has 135 feet of sand and gravel. Mr. Kimball's well, near the station in Brookville, altitude 666 feet above tide, penetrated 160 feet of drift, thought to be mainly gravel. About 4 miles below Brookville a gas boring at an altitude of 600 feet penetrated 154 feet of sand and gravel before striking rock.

BOWLDERS.

There are not many surface bowlders associated with this moraine or the inner border tract, but their occasional occurrence on the surface in places where there has been scarcely any erosion distinguishes this moraine and the district north of it from the older drift tract toward the south, on whose uplands the bowlders are concealed by silt.

One very large gneiss bowlder on Mr. Perrine's land, near the "Rock schoolhouse," about 3 miles southeast from Lebanon, was mentioned by Orton.[1] It measured 17 by 13 by 8 feet, and slopes outward at the base as though still larger under ground. Near the road between Waynesville and Harveysburg, on the elevated uplands, the writer observed a bowlder about 8 feet in diameter and 3 to 4 feet high. By far the largest transported rock mass ever reported from Ohio is that which Orton mentions in his report

[1] Geology of Ohio, Vol. III, p. 339.

on Warren County.[1] It is a large mass of Clinton limestone, covering about three-fourths of an acre and having a thickness of 16 feet. It is found east of Little Miami River near Freeport, and is 2 to 3 miles outside the limits of the Wisconsin drift. It overlies Illinoian till and other drift material. It was thought by Orton to have been derived from the outcrops west of the river, but in the writer's opinion it was more probably derived from the northeast. This opinion is based on the fact that the striæ at Wilmington, a few miles to the east, that underlie the Illinoian drift, and are therefore connected with an ice movement as early as this bowlder transportation, have a southwestward bearing.

STRIÆ.

Observations of striæ are not rare in the district covered by the Miami lobe, there being thirty-three recorded within this district south of the Wabash moraine. None have been observed outside the moraine under discussion, but between this moraine and the next succeeding one there are seventeen observations. Of these four are in Wayne County, Ind., and bear west of south toward the western limb of the moraine; three are in Butler County, Ohio, and bear southward toward the point of the morainic loop; the remainder are in the district between the Great and Little Miami rivers, and bear southeastward toward the eastern limb of the moraine. The glaciation, therefore, harmonizes well with the distribution of this moraine, the striæ in nearly every instance being directed toward the moraine. Plummer, many years ago, discussed striæ discovered by him near Richmond.[2] They are of interest, not only because of their value in indicating the direction of ice movement, but also because they are apparently the first striæ ever reported from that State. They are found in a quarry of blue limestone on the west side of a small stream tributary to the East Whitewater, 2 miles north of Richmond. A very hard clay rested on the striated surface, and above this deposit were gravel, sand, clay, and soil, the whole occupying 15 feet. The bearing of the striæ is S. 20° W. Plummer gives the following description:

> The grooves vary from a mere scratch to furrows an inch or more wide, and with one or two exceptions running exactly parallel with each other. The average depth of these grooves is perhaps one-eighth of an inch, and their breadth and shallowness give to the surface of the rock a vittated appearance.

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[1] Geology of Ohio, Vol. III, p. 285.

[2] Suburban Geology of Richmond, Indiana, by John T. Plummer: Am. Jour. Sci., 1st series, Vol. XLIV, 1843, pp. 281–313.

Other interesting observations on the drift formations are reported by Plummer in equally graphic manner. They relate to the occurrence of silts containing blue spots thought to be "tanno-gallate of iron," from which he made an ink; also to organic remains in the drift, and to the number and kinds of bowlders on the surface.

The following observations of striæ in Indiana are recorded in the State geological reports for 1859 and 1878: On page 43 of the earlier report, striæ near Cambridge in a quarry in NE. $\frac{1}{4}$ of sec. 33, T. 16 N., R. 12 E., about a mile west of Whitewater River, are said to have a bearing from north of northeast to south of southwest. In the later report (pp. 184–185), striæ at the falls of the west fork of East Whitewater, near the locality noted by Plummer, north of Richmond, have a bearing of S. 40° W. Striæ in the bed of Nolands Fork, near Centerville (p. 215 of same report), bear slightly west of south.

In Butler County, Ohio, striæ, whose bearing is nearly north to south,[1] were observed by G. F. Wright about 4 miles east of Hamilton on the southeast bluff of the Great Miami. Concerning these striæ Wright remarks:

> These are of additional interest as showing the degree to which the ice movement at this point was independent of the local topography. The striæ here observed were upon the south side of the Miami River (whose general course is here northeast and southwest), and 75 feet above low-water mark. The direction of the striæ is diagonal to that of the valley, which is here a mile or more in width, but nearly at right angles to the general course of the glacial boundary, about 20 miles to the south.

Orton personally mentioned to the writer that he had observed striæ on the uplands northeast of Oxford which have a bearing nearly south.

About 3 miles southwest of Middletown, on the west bluff of the Great Miami, is a glaciated exposure in which the striæ bear S. 8° E. (magnetic).

In Warren County, Ohio, about 3 miles northeast of Springport, on elevated uplands at Brown's quarry, striæ bear S. 48° E. (magnetic).

Three miles west of Waynesville the bearing is S. 48° E., while 3 miles northwest, near the village of Lytle, the bearing is S. 70° E.

Orton's map, opposite page 413, Vol. I, Geology of Ohio, indicates striæ in the vicinity of Lytle bearing S. 66° E. and S. 54° E., while near Centerville the map shows striæ bearing S. 80° E. In the vicinity of Yellow Springs and Springfield, and below Springfield, along Mad River

[1] See Bull. U. S. Geol. Survey No. 58, 1890, pp. 41–42.

bluffs, observations made by Orton, and later ones by Chamberlin, give the striæ a bearing S. 8°–12° E.

About 4 miles east-northeast of Urbana, in a quarry south of Long's station, there are exposures of striæ which bear about E. 10° N. The eastward movement is clearly indicated on the rock surface, whose prominences show plainly that their west side is the stoss side. This bearing is nearly at a right angle to a moraine in which this quarry is situated, whose trend in that vicinity is from slightly west of north to east of south (see Pls. II and XI).

INNER BORDER DISTRICT.

The district which lies between the Hartwell moraine and the next later one (the outer moraine of the late Wisconsin series) comprises only a few counties in southwestern Ohio and southeastern Indiana. Its extent may be seen by reference to the map of the Maumee-Miami lobe (Pl. XI).

TOPOGRAPHY.

The features are somewhat diversified. The Ohio portion is hilly, except near the border of Indiana in Preble and Butler counties. The hills have rock within a few feet of the surface; the main drainage lines remain essentially the same as in preglacial times. The valleys of this region, especially those of streams like Fourmile, Sevenmile, and Indian creeks, are characterized by a peculiar filling with till. The till is several times as deep as on the uplands, and is level topped or nearly so, giving the appearance of a terrace when viewed from the uplands. In the lower portions of these streams the till has been channeled to a depth of 75 to 100 feet, and forms an inner and lower bluff. Above these lower bluffs of till stand the rocky upland tracts 200 to 300 feet or more higher than the streams. The plane surface which the till presents in these valleys is perhaps no more remarkable than that of upland plains. Had the amount of drift been sufficient to have nearly filled the valleys the plane surface would scarcely suggest a terrace.

Two valleys in this inner border district, Mill Creek Valley and a valley leading from the Little Miami at Kings Mills to the Great Miami at Middletown, resemble the valleys above mentioned in having level-topped plains in them, but a view of these plains from bordering uplands does not suggest a terrace, since the small streams now occupying them have scarcely

begun the excavation of a valley, and the size of the plain is much more out of proportion to that of the present streams than the plains along Fourmile, Sevenmile, and Indian creeks.

In northeastern Franklin, in Union, and southeastern Wayne counties, Indiana, and in a narrow belt in southwestern Preble and northwestern Butler counties, Ohio, the uplands are strikingly in contrast with those just described. Instead of being hilly the surface is level and poorly drained, and the valleys do not have the depth and size of those draining the adjoining tracts in southwestern Ohio. The valleys are nearly all of postglacial age, the preglacial drainage being obscured except in the main lines, such as the Whitewater River and lower portions of the tributaries of that stream in northeastern Franklin County, Ind.

There is but little surface undulation in this level tract, the till swells, as a rule, being scarcely 5 feet in height. There is, however, a ridge-like accumulation in Union County that merits notice, though its significance was not determined. The writer's attention was directed to it because of its prominence on the profile of the Cincinnati, Hamilton and Indianapolis Railway, which had been examined by him before he visited that district. The profile led to the suspicion that the ridge is a moraine, but upon reaching the ground it proved so inconspicuous a feature that the suspicion was scarcely confirmed. It has as smooth a surface as the bordering plains, and might be crossed by the traveler without appreciation of its real height. The profile gives the following data:

Profile over ridge in eastern Union County, Ind.

Location.	Distance from Hamilton.	Altitude.
	Miles.	*Feet.*
East base	23.00	475.0
Crest	23.875	509.9
West base	24.60	470.5

The slope on the east continues to College Corners and on the west to the creek west of Lotus, but is less rapid than on the ridge. The trend of the ridge is nearly north-south, but it dies away in either direction within a mile or two from the railway. It has been penetrated about 30 feet by wells and no rock strata have been struck.

STRUCTURE OF THE DRIFT.

The drift of this inner border district, like that forming the moraine, consists largely of typical till, which has a clayey matrix with liberal admixture of pebbles. There are a few gravel knolls and ridges on uplands and also along valleys. Portions of the valley filling present a horizontal bedding in which sandy partings separate till beds or beds of stony clay; but the greater part of the filling, like that on the upland, appears to be typical till without distinct horizontal bedding.

Wright has given views of two exposures of the till in the valley plain of Fourmile Creek, in Bulletin No. 58, which are here reproduced in Pl. XII, *A* and *B*. The till represented in the first view is a typical deposit, which is nearly level topped and is banked against the base of a high, rocky bluff that within a mile toward the south rises to 300 feet or more above the creek. The exposure in the second view presents lamination, and in places there is clear evidence of water bedding. The large stones appear to have been dropped by ice into a stream which had only a sluggish current. The eastern part of Oxford is on a flat-surfaced till plain, along the same creek, whose surface stands fully 100 feet below the high rocky bluff on which the rest of the town is situated and nearly 100 feet above the creek bed.

There is scarcely an exposure of rock along the postglacial valley of Fourmile Creek from the junction of the three forks above Oxford to its mouth. The record of but one well was obtained along this valley. This well is at Brazil Inman's, about 1 mile above the mouth of the creek. It is 104 feet deep, and penetrates 90 feet of till, below which it is in sand and gravel. It is reported that "snail shells" and small twigs were pumped out from the sand near the bottom of the well.

What percentage of drift in the valleys is of the age of the moraine under discussion, and what of the earlier or Illinoian age, can scarcely be determined from the facts at command. The freshness of the exposed portion of the drift along Fourmile, Sevenmile, and Indian creeks leads the writer to consider it of the same age as the moraine. The shells and twigs reported above, which were pumped from sands beneath the till near the mouth of Fourmile Creek, may be of interglacial age, and mark the line between the Wisconsin and the earlier drift sheet. The occupancy of Mill

A. SECTION OF TILL AT LANE'S MILL NEAR DARRTOWN, OHIO.

B. EXPOSURE OF TILL SOME MILES EAST OF LANE'S MILL SECTION.

Creek Valley, in Hamilton County, and also the abandoned valley connecting the Little and Great Miami valleys, in Warren County, by this moraine, and the freshness of the drift there exposed, indicate that the upper portion at least was deposited contemporaneously with the moraine. However, the well sections in Mill Creek Valley south of the moraine seem to suggest that much of the filling may have taken place in the earlier advance.

As above noted, there is some uncertainty whether the lowland tract connecting the Little and Great Miamis through western Warren County contains a deep buried channel or waterway capable of carrying a stream from one valley to the other, for the reason that rock is struck at slight depth in wells in the western part of the swampy tract connecting these streams. A well at Mrs. Stewart's, on the east side of the county line road (between Warren and Butler counties), struck rock at 13 feet, and one at Mr. Schwab's, about one-half mile farther north, at 20 feet. These are both in the valley, the latter being near its center, the former near the south side. Such meager evidence does not, however, preclude the possibility of a deep channel existing in this low belt, though it throws doubt on its occurrence.

A few records of wells were obtained in the Indiana portion. Mr. Burt, a well driller residing at Liberty Ind., who has made wells on the drift ridge near Liberty, noted above, reports that they penetrated yellow and blue till to a depth of about 30 feet, and then entered a black earth into which they were carried for a foot or two, the deepest well being 33 feet. In a well on the east slope at Mr. Bamon's, one-half mile north of Cottage Grove, Mr. Burt found many bowlders about 30 feet below the surface. Possibly an old land surface or stream bed was reached at this well. Two other wells were reported by Mr. Burt which may have passed into a drift older than Wisconsin in their lower portion. At Beechy Mire post-office Mr. Lybrook's well entered a yellow clay below the blue till at a depth of 33 feet. At Salem, about 3 miles southeast of Liberty, Mr. Burt made a well which passed through the following beds:

Section of a well southeast of Liberty, Ind.

	Feet.
Yellow till	8–10
Blue till	25
Yellow clay, not noticeably pebbly, at bottom of well.	

At Weibels Corners, 4 miles northeast of Liberty, Mr. Burt made a well in which the blue clay below the surface yellow till was peculiarly soft, sticky, and free from pebbles, so that it could be unrolled from the auger like putty. In Liberty, at the Pyle House, a bed of muck and leaves was struck by the same well driller about 35 feet from the surface, below a blue till. Between the muck and the underlying rock was a sand bed 15 feet in thickness.

In Liberty two gas wells have been made, of which one, on high ground in the east part of town, penetrated about 90 feet of drift; the other, on low ground in the west part of town (29 feet below the level of the railroad station, or 940 feet above tide), penetrated 70 feet of drift, mainly till. The drift in these wells is much thicker than the average on uplands in Union County. In the southeastern part of the county the thickness averages scarcely 10 feet over a tract comprising several square miles; and the large creeks in the county, which have cut channels 30 to 50 feet below the level of the uplands, usually reach the rock. It is probable that the average thickness is not more than 50 feet.

In southeastern Wayne County, also, the deeper ravines reach the rock at 50 to 60 feet below the upland plain, which in the vicinity of the village of Boston is very level.

Two short gravel ridges, which should perhaps be classed as eskers, were observed in the north part of Warren County, Ohio, east of Springboro. The longer one has a length of about a mile and trends west-northwest to east-southeast, while the shorter one has a length of about one-half mile and trends north to south. The shorter one has its southern terminus in Clear Creek Valley about a mile east of the eastern terminus of the longer one, the latter being situated entirely in Clear Creek Valley. The bearing of striæ in that vicinity, as shown above, ranges from about southeast to S. 70° E. The longer ridge, therefore, approaches more nearly the direction of the striæ than does the shorter one, but neither is strictly in harmony with them. At the southern end of the shorter ridge a spur leads off abruptly to the east for a few rods and there dies away. This turn of the southern end of the shorter ridge and the bedding in the longer ridge indicate that the direction taken by the water which formed the ridges was eastward, or the reverse of the present course of drainage along Clear Creek. No delta deposit nor eastward continuation of gravel deposits was found beyond the

shorter ridge. There are gravel knolls along the Little Miami Valley, near Waynesville, about 5 miles to the east, but the distance from the gravel ridges is so great that it is doubtful if the same stream that formed either of of them also formed the gravel knolls.

The longer ridge is interrupted near its eastern end by a slight gap (a feature not unusual in eskers). Its greatest height is 30 to 40 feet, while portions are 20 feet or less. Its width, including slopes, is 100 to 200 yards. Its surface is somewhat irregular, as if there had been uneven deposits of englacial drift upon it after the body of the ridge had been formed. This view finds support in the fact that in Bennett's gravel pit, which opens the ridge to view near its eastern end, there is a change from gravel to till in passing from the center to the north slope of the ridge, the till here being confined to the lower portion of the slope. The exposures are not sufficient to show whether or not the till in places reaches the crest of the ridge. Bennett's pit shows great variations in the bedding of the gravel, in dip and thickness, as well as in coarseness of material. The lower part of the pit is more largely gravel than the upper, there being beds of nearly clear sand near the top of the ridge.

The shorter ridge has a height of 10 to 12 feet and breadth of 50 to 100 yards, including slopes. It is opened at Blackford's pit, its cross section being well shown. The surface beds arch over, but the deeper beds are horizontal beneath the center of the ridge. This arching of the surface beds may have been produced in the manner suggested by Russell,[1] in his article on the glaciers of the Mount St. Elias region. The view is there expressed that gravel ridges of this class are built up in horizontal beds in tunnels in or beneath the ice sheet, and that upon the disappearance of the ice walls the material next the borders is left unsustained, and therefore settles down, giving the arched appearance to the surface beds. This short ridge has a much smoother surface than the larger one and apparently has no capping of till. At Blackford's pit it is composed mainly of gravel of medium coarseness, there being but little sand and but few cobblestones intermixed. In both ridges the pebbles are composed largely of limestone rocks, not a small percentage being the local rocks.

Near the mouth of Clear Creek, in Franklin, and for a mile or more southeast from that village, drift knolls are numerous. They range in

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[1] I. C. Russell: Am. Jour. Sci., March, 1892.

height from 10 feet up to fully 60 feet and are sharp and nearly conical. They are all in a lowland tract on the south side of the valley, their bases being but 40 to 50 feet above Clear Creek, while the uplands on the south rise to a height of fully 200 feet above the creek. Occasional gravel knolls occur along Clear Creek Valley between this group and the western end of the large gravel ridge. They appear to contain much gravel and may owe their presence in this lowland tract to the same stream which formed the ridge, though the method of deposition is even more problematical than that of the ridge.

CHARACTER OF THE OUTWASH.

In the district outside the Hartwell moraine three quite distinct classes of deposits appear above the consolidated rocks: First, the earlier or Illinoian drift which, covering the uplands, extends south to the glacial boundary; second, the silt deposits which cover the Illinoian drift and extend into the unglaciated districts; third, the morainic outwash, including the gravel aprons and such valley drift as seems to be connected with the moraine. The first and second having been considered, it remains only to discuss the third class. In connection with this the gravel aprons and valley drift in the reentrants are also considered.

In the reentrant between the Scioto and Miami lobes there is a complex series of gravel plains. Probably all are of somewhat later date than the Hartwell moraine, and the latest are of late Wisconsin age. The broad gravel plain leading down Mad River is evidently of late Wisconsin age, the source of the gravel being in the late Wisconsin moraine, which encircles the head of the river. East from the valley of Mad River there are other gravel plains, which are somewhat older than the one along the stream. One which leads from West Liberty southward past King's Creek Station to Urbana, connecting both at the north and south with Mad River, stands but little above the Mad River gravel plain and may also belong to the late Wisconsin series. It appears to be an outwash from a weak moraine lying between it and Mad River Valley.

East from this gravel plain there is a prominent moraine, noted above, which extends from southern Logan County, southward past Urbana, to Springfield, as indicated on the glacial maps, Pl. II and XI. On the east side of this moraine a gravel plain appears which leads southward near the east border of the Mad River drainage basin to the headwaters of the Little

Miami, in a course singularly out of harmony with the present system of drainage, its course being directly across Mackocheek, Long, Buck, and Beaver creeks. It connects with the Little Miami Valley east of Springfield near Thorpe station and, swinging to the southwest, follows down that valley. The width ranges from a half mile or less up to nearly 2 miles.

There is a marked southward descent along this gravel belt, the altitude above tide being near Kennard 1,185 feet, east of Urbana about 1,150 feet, at Catawba station 1,090 feet, at New Moorefield 1,060 feet, and at the point of connection with the Little Miami drainage near Thorpe about 1,030 feet. The general elevation of this gravel belt is about 100 feet above the gravel plain along the neighboring portion of Mad River Valley, and, as it is distant from that valley only 3 to 6 miles, through much of its course within the present Mad River drainage basin, the descent toward Mad River is more rapid than along the line which the old stream followed. It is for this reason that the eastern tributaries of Mad River now pass directly across this old line of drainage.

The course selected by the old stream appears to have been just outside the Miami ice lobe at a time when Mad River Valley was buried beneath the ice. The moraine which lies west of the gravel plain bears out this interpretation, for it seems to be of the same age as the gravel plain, and knolls in places come down to the level of and merge into the plain. The eastward-bearing striæ near Urbana also show that the Miami ice lobe extended about to this gravel plain. On the east side of this plain there is a blufflike border which indicates that the drift on that side was exposed for erosion and hence is probably somewhat older than that on the west. Its freshness, however, is such as to place it within the early Wisconsin glacial stage.

The gravel plain has been eroded to a markedly greater degree by the streams that cross it than the late Wisconsin terraces on the same streams. It has been cut down from a level 20 or 30 feet and occasionally 50 feet above the late Wisconsin terraces, while those terraces are seldom 50 feet above the present stream. There is also a broader excavation above the level of the late Wisconsin terraces than below, which makes the contrast still more striking. As erosion in gravel is a comparatively slow process under ordinary conditions, these features seem to indicate that an interval of considerable length separates this gravel deposit from the late Wisconsin gravels along Mad River and its tributaries.

It seems probable that the ice sheet had melted away from the portion of the Little Miami Valley below the point where this belt of gravel connects with the river before the gravel deposition occurred, for latitude and the heat radiated from an extensive land surface would favor melting there, while the ice sheet still held its ground in the part of the reentrant to the north.

There are gravel aprons associated with morainic knolls and ridges along this part of the Little Miami which are probably somewhat older than the long belt of gravel just discussed. The most conspicuous is the plain immediately west of Xenia, known as "Cherry Bottoms." There is also a small gravel plain east of Spring Valley. The Cherry Bottoms plain rises toward the moraine which borders it on the north and west, and fits about its knolls and ridges. It also contains numerous basins along the border next the moraine. This gravel plain is now drained southward to the Little Miami, through a valley utilized by the Little Miami Railway in rising from the river valley to Xenia. It is not certain whether the glacial waters followed this route or passed southward to Cæsars Creek along the ice margin; perhaps both routes were used in the course of the formation of the moraine.

The small gravel plain east of Spring Valley stands at its western border more than 100 feet above the Little Miami River. There is a bed of gravelly knolls along this border which overlook Spring Valley and serve as a water parting between the Little Miami and Cæsars Creek; and south from there a till ridge causes the water to run from within one-half mile of the bluff of the Little Miami eastward to Cæsars Creek. It is probable that the glacial waters which formed this gravel plain, like those of the present system of drainage, escaped through Cæsars Creek.

On the west side of the Little Miami, 1 to 2 miles below Spring Valley, there is a small gravel plain which, though it lies near the inner border of the moraine, was probably formed by waters of glacial age. It stands fully 100 feet above the river, extends back about one-half mile from the bluff, and is a mile or more in length. There seems to be no terrace of corresponding height along the Little Miami below this plain. Its origin is therefore not clearly understood.

Near the mouth of Cæsars Creek there are, on the east side of the river, gravel beds at levels about 150 feet above the stream but they are

not clearly outwash deposits, being disposed in arching and oblique beds. One gravel pit exhibits beds which dip sharply eastward toward the bluffs.

Gravel terraces apparently of glacial age are well defined along the Little Miami, below the point where the moraine crosses, but they are surprisingly low down, the general altitude of the upper terrace being but 50 feet above the river. In the vicinity of Kings Mills the moraine comes down to the borders of this terrace at the low altitude just named, thus indicating that no higher glacial terrace exists which can be correlated with this moraine. Upon approaching the Ohio the river descends more rapidly than the terrace; as a consequence the same terrace that stands 50 feet at Kings Mills stands about 100 feet above the river at its mouth. The altitude of the terrace at the point where the river leaves the moraine (near the mouth of Cæsars Creek) is about 730 feet above tide, while at the mouth of the stream it is but 530 feet, a fall of 200 feet in 40 miles The present bed of the river falls 250 feet in this distance. The material embraced in the terraces varies greatly within short distances, showing a range from fine pebbles, well rounded, up to coarse subangular blocks, but the variations may, in many instances, be readily accounted for. For example, at Loveland the terrace is loaded with local limestone slabs which are thought to have been brought in, in part at least, by the freshets on a tributary which enters the river there from the east. Instances were noted where blocks of local limestone were derived from projecting points a short distance upstream, and it is possible that the blocks at Loveland were in part derived from such sources.

In many instances the coarseness of the material varies in accordance with the curve of the stream, being much coarser on the outer than on the inner curve. Where unaffected by these local influences the material in the terrace consists of well-rounded gravel with but a slight intermixture of sand or earthy material. The pebbles, like those in the moraine, consist largely of local rocks, the Canadian rocks forming less than 5 per cent of the material. The gravels present a remarkably fresh appearance, the surface of limestone pebbles slightly embedded, as well as those at some depth, being scarcely at all oxidized, while pebbles of crystalline rocks seldom show signs of disintegration. In these respects the pebbles are decidedly in contrast with those of gravels in the earlier drift whose limestones, when slightly embedded, are deeply oxidized and whose crystalline

pebbles are to a large extent disintegrated. The calcareous material with which the waters that percolate this terrace are charged forms a slight cementation of portions of the terrace from which the water is removed by evaporation.

The terraces of the Little Miami were probably built up in part by glacial streams from the vicinity of Kings Mills, where the ice sheet came down to the borders of the valley, as well as from the point where the moraine crosses the stream near the mouth of Cæsars Creek, and from the Scioto lobe along Todds Fork. It is not known whether glacial terraces lead in from the East Fork, that stream not having been examined. On account of these numerous lines of discharge, the lower portion of the Little Miami Valley and the portion of the Ohio Valley immediately below the mouth of the Little Miami were greatly filled by gravel, there being in the city of Cincinnati a filling from a level somewhat below the present stream to a level about 110 feet above it, the greater part of which is gravel with but a slight admixture of sand and earthy material.

As above noted, statements that the rock floor of the Ohio Valley at Cincinnati stands 120 to 200 feet below the present bed[1] are probably due to confounding the terrace with the river bed, which would make a difference of about 110 feet. After careful inquiry the writer could learn of no wells within the city limits which show the rock floor to be lower than 75 feet below low-water mark. Records of wells were obtained at various parts of the city showing the distance to rock in the midst of the valley as well as on its borders, as follows:

East End Gas Works, near north bluff, penetrated 130 to 135 feet of drift, striking rock at 70 to 75 feet below low-water mark.

West End Gas Works, in midst of valley, penetrated 118 feet of drift, striking rock at 58 feet below low-water mark.

Storr's distillery (formerly Gaff's), west of Mill Creek, near mouth, has one well that struck rock at 40 feet below low-water mark, while thirteen others failed to strike rock, though terminating at levels 40 to 50 feet below low-water mark.

The pier on the Ohio side of the suspension bridge rests on rock at about 40 feet below low-water mark, while the middle pier of the Chesapeake and Ohio Railway bridge was reported by Joseph F. James to rest

[1] See Geology of Ohio, Vol. I, 1873, p. 433; also Bull. U. S. Geol. Survey No. 58, 1890, pp. 79–80.

on rock at a level about 60 feet below the river bed. The well at the Hotel Emory penetrated 150 feet of drift and is thought to be on rock at the bottom 40 to 50 feet below low-water mark. A well on Sixth street, between Horn and Harriet streets, in the midst of the valley, struck rock at only 10 feet below low-water mark. On the Kentucky side, west of the Licking River, the rock comes down to the river bank, and the middle pier of the Ludlow bridge rests on the rock at the level of the present river bed (J. F. James).

No accurate records were obtained between Cincinnati and Lawrenceburg, Ind., along the supposed new course of the Ohio. Rock is struck in Lawrenceburg at about 40 feet below the river, the rock floor being reported by the State geologist of Indiana to have an altitude 368 feet above tide.

The valley of Mill Creek afforded a line of escape for waters from the point of the glacial lobe, but it seems to have been less vigorous than that along the Little Miami. Well sections at Ivorydale and Cumminsville, and observations along the creek, show that with the exception of a few feet at the surface the drift is largely clay. There is a deposit of surface gravel along the west side of the creek as far north as Hartwell, above which, in the villages of Wyoming and Lockland, there is till. On the east side of the creek the gravel extends up at least to Reading. Not far above this village the whole width of the valley is occupied by a deposit of till. The gravel, therefore, appears to head in the moraine. Sandy deposits on the east border of Mill Creek Valley, in the vicinity of Bond Hill, as above noted, may prove to be the product of flooded stages of the glacial stream that issued from the ice sheet near Reading.

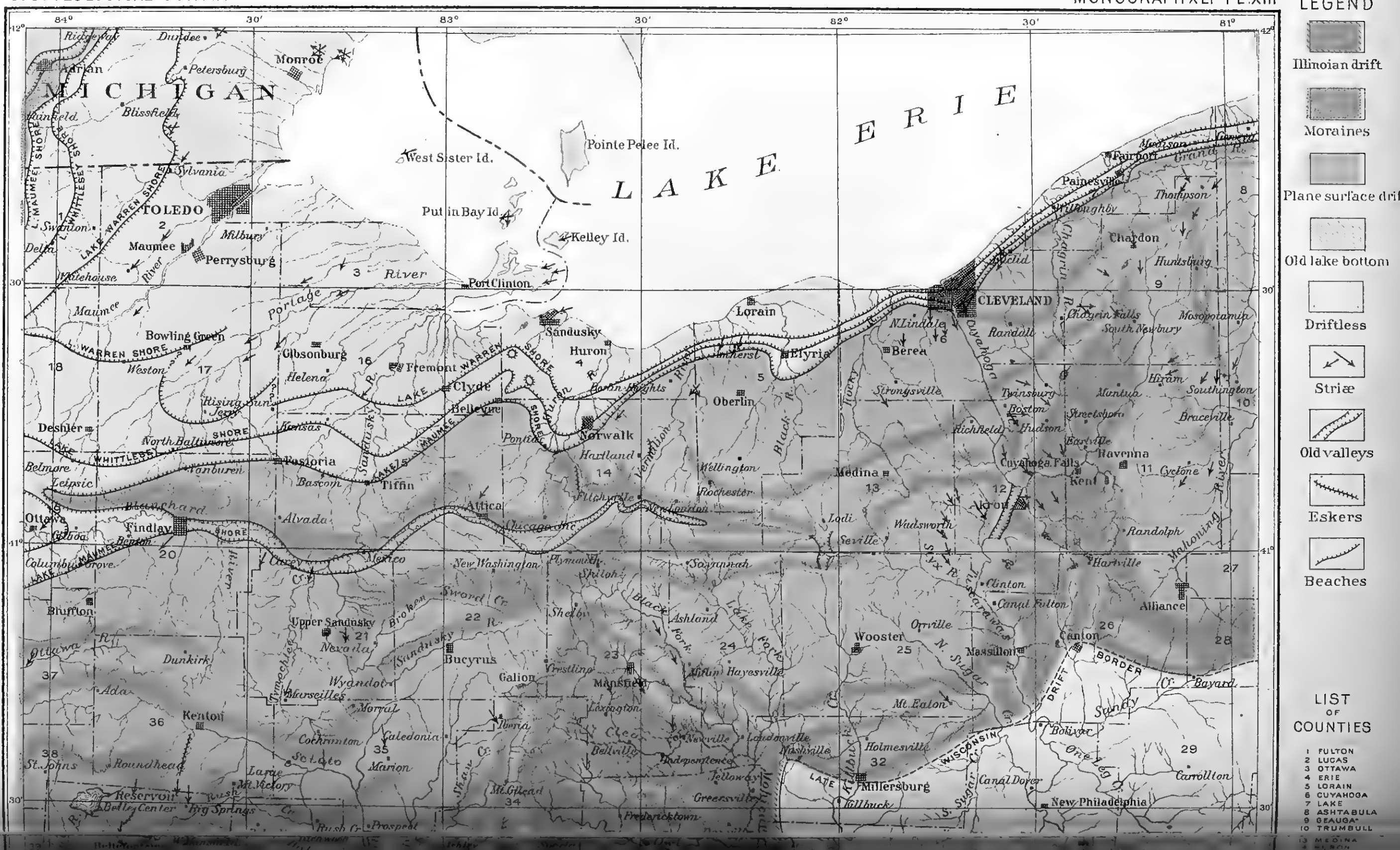
In the Great Miami Valley there is a heavy accumulation of gravel, having a breadth of 1 to 3 miles, and a depth, in the deepest part of the valley, of about 200 feet. The surface portion of this gravel probably was deposited during the formation of later moraines and the deep portion at the Illinoian or earlier Wisconsin. Similarly, on the Whitewater River, there is a great accumulation of gravel whose surface portion apparently was deposited in large part at the time when later moraines were being formed, since the gravel plain extends to these later moraines. However, there has been found no evidence that the escape of waters was not copious in each of these valleys at the time the outer moraine was forming. If the valley was built up to a higher stage at this time than when later moraines were forming the remnants of its terraces have escaped notice.

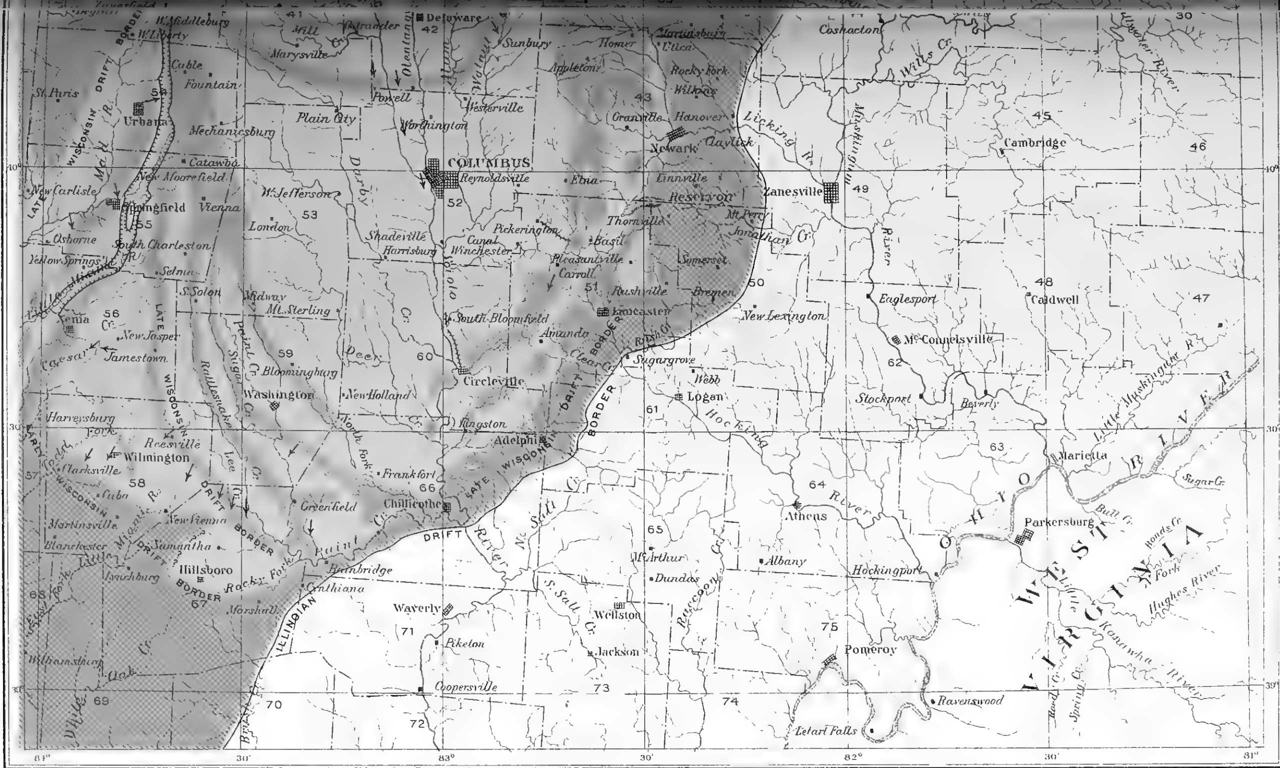
SECTION II. EARLY WISCONSIN DRIFT OF THE SCIOTO LOBE.

INTRODUCTORY STATEMENT.

The Scioto lobe, as indicated in Pl. XIII, covered nearly one-half of the glaciated portion of Ohio, and occupied the ground between the Grand River lobe on the east and the Miami lobe on the west. It was differentiated into an eastern and western portion by a highland tract near Mansfield, but in the former portion the lobation was slight compared with that in the latter, and the striæ indicate that it had not such perfect divergent movement as is commonly displayed by glacial lobes. It is therefore classed as a shoulder or lateral extension of the main lobe.

The outline of this lobe and its shoulder, together with the bearing of the striæ, show a striking dependence upon the physical features of the region, the movement being greatly extended along the axis where low altitude and a smooth surface prevailed, and but slightly extended over elevated and hilly districts which border the basin. A feature of much significance is found in the winding course of the axial movement, which shows a tendency to accommodate itself to the lowest parts of the district traversed. This is well shown by the striæ. In passing from the western end of the Lake Erie Basin to the Scioto Basin the movement changed from a southwestward to a southward course. Within the Scioto Basin the movement was slightly east of south to the vicinity of Columbus, beyond which it turned southwestward, there being a lower and smoother tract of country in that direction than down the Scioto. At its terminus at the outer moraine in Clinton and Highland counties it fronted nearly southwest. This winding course of the axial movement is in accord with the view that previous to the last ice invasion the topography was similar to what it is now. Indeed, all the striking peculiarities of outline which this glacial lobe presents—the reentrant angle at the highlands between the Grand River and Scioto lobes, the shelf at the highlands near Mansfield, the long lobe in the Scioto Basin, the winding course of the ice tongue in passing from the Lake Erie Basin to the extremity of the lobe, and the reentrant angle at the highlands between the Scioto and Miami lobes—seem to be dependent upon topography that was essentially the same previous to this ice invasion as it is now. No doubt considerable abrasion resulted from each of the ice invasions, but no evidence has been


LEGEND
Illinoian drift
Moraines
Plane surface drift
Old lake bottom
Driftless
Striæ
Old valleys
Eskers
Beaches
LIST OF COUNTIES
1 FULTON
2 LUCAS
3 OTTAWA
4 ERIE
5 LORAIN
6 CUYAHOGA
7 LAKE
8 ASHTABULA
9 GEAUGA
10 TRUMBULL
LAKE ERIE
MICHIGAN
TOLEDO
CLEVELAND
Monroe
Sandusky
Lorain
Elyria
Oberlin
Norwalk
Fremont
Tiffin
Fostoria
Findlay
Bowling Green
Medina
Wooster
Mansfield
Bucyrus
Canton
Massillon
Akron
Kenton
Millersburg
New Philadelphia
Alliance
Painesville
Fairport
Chardon
Port Clinton
Put in Bay Id.
West Sister Id.
Pointe Pelee Id.
Kelley Id.
LAKE WARREN SHORE
L. WHITTLESEY SHORE
L. MAUMEE SHORE
WISCONSIN DRIFT BORDER



MAP OF THE SCIOTO GLACIAL LOBE

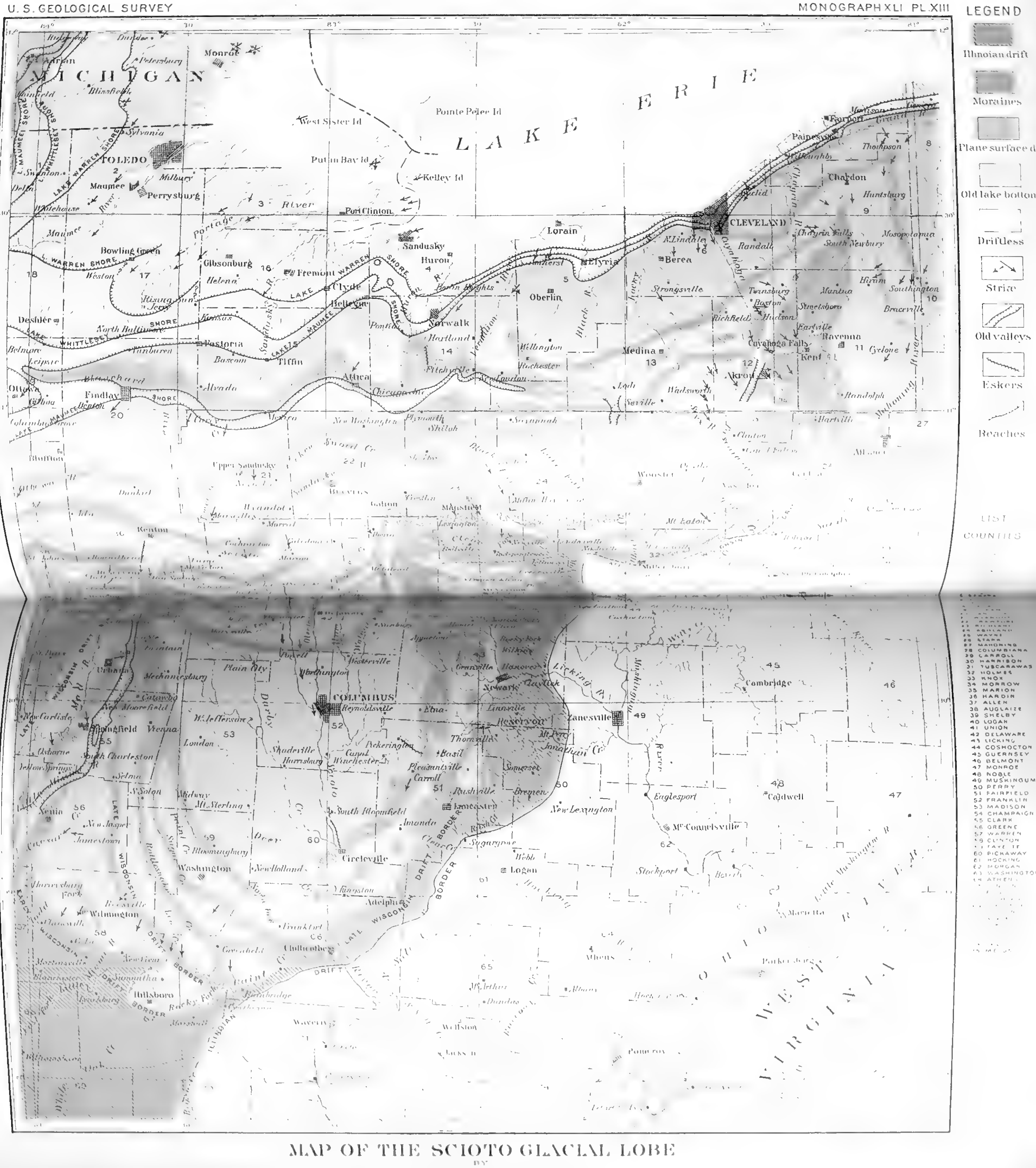
BY

BY FRANK LEVERETT

Scale

5 0 5 10 15 20 25 MILES

18 SANDUSKY
19 PUTNAM
20 HANCOCK
21 WYANDOT
22 CRAWFORD
23 RICHLAND
24 ASHLAND
25 WAYNE
26 STARK
27 MAHONING
28 COLUMBIANA
29 CARROLL
30 HARRISON
31 TUSCARAWAS
32 HOLMES
33 KNOX
34 MORROW
35 MARION
36 HARDIN
37 ALLEN
38 AUGLAIZE
39 SHELBY
40 LOGAN
41 UNION
42 DELAWARE
43 LICKING
44 COSHOCTON
45 GUERNSEY
46 BELMONT
47 MONROE
48 NOBLE
49 MUSKINGUM
50 PERRY
51 FAIRFIELD
52 FRANKLIN
53 MADISON
54 CHAMPAIGN
55 CLARK
56 GREENE
57 WARREN
58 CLINTON
59 FAYETTE
60 PICKAWAY
61 HOCKING
62 MORGAN
63 WASHINGTON
64 ATHENS
65 VINTON
66 ROSS
67 HIGHLAND
68 CLERMONT
69 BROWN
70 ADAMS
71 PIKE
72 SCIOTO
73 JACKSON
74 GALLIA
75 MEIGS



MAP OF THE SCIOTO GLACIAL LOBE

BY FRANK LEVERETT

Scale

found to support the view that it was markedly greater in the basins than on the elevated hilly tracts that border them. On the contrary, evidence against great excavation is found in the district south of the glacial boundary near the southern extremity of this glacial lobe where the two types of topography are nearly as much in contrast as within the glaciated district, there being east of the meridian of Hillsboro, Ohio, and Maysville, Ky., a more elevated and more hilly district than there is west of that meridian. For further discussion of topographic features see Chapter II.

THE OUTER OR CUBA MORAINE.

An earlier moraine than the outer one described by Chamberlin[1] was discovered by the writer in the southwestern part of the district covered by the Scioto lobe. It is apparently to be classed with the early Wisconsin series, while the one described by Chamberlin seems to belong to the late Wisconsin series. So far as recognized, it lies outside the later ones only in the southwestern part of the district, though it may possibly have correlatives in portions of the tangled systems of moraines formed on the eastern side of the lobe. The name Cuba is taken from a village that stands on the crest of the moraine near the middle of the morainic loop.

DISTRIBUTION.

On the north side of "Beech Flats," in Pike County, and near the eastern line of Highland County, Ohio, this moraine becomes clearly separated from, and distinctly developed outside of, the later ones. It is readily traced westward along the south side of Rocky Fork, from the mouth to the source of that stream, the villages of Cynthiana, Carmel, and Marshall being situated near its southern margin and Hillsboro just north of it. Its breadth is 1 to 2 miles. In the vicinity of Hillsboro the creek winds among sharp gravelly knolls, which have a contour strikingly different from the remainder of the belt, and which may prove to belong to the earlier drift sheet. Northwest of Hillsboro the moraine for several miles is not well developed, but a mile or two southeast of New Vienna it reappears in considerable strength. From that point it takes a westward course, its outer margin being in surveys 2357, 753, 4656, 4233, and 4234, Highland County. Continuing westward into Clinton County its margin at the East Fork of

[1] Third Ann. Rept. U. S. Geol. Survey, 1883, pp. 339–341.

Little Miami River is at the crossing of the Martinsville and Hillsboro pike. From this stream westward to Martinsville the pike runs near the south margin of the moraine, keeping the outer border plain constantly in view. Martinsville is itself on the south slope. West from that village the moraine leads through Cuba, its southern edge being followed by the East Fork of Cowans Creek to its junction with Todds Fork, near Clarksville. From this point it swings rapidly northward and, assuming a course slightly west of north, comes to Cæsar Creek, near Harveysburg, where it connects with the eastern limb of the outer, or Hartwell, moraine of the Miami lobe. The interlobate moraine, as above noted (p. 305), extends up the Little Miami Valley across Greene County. This belt exhibits its greatest breadth near Cuba, where for a few miles it has a width of 4 or 5 miles; usually its width is but 1 or 2 miles.

RELIEF.

North of Beech Flats, in Pike County, and in southeastern Highland County, the moraine is of a subdued type, and stands only 10 to 25 feet higher than the north border of these flats. Toward the west sharp gravel hills, 80 to 100 feet in height, set in, among which are low tracts no higher than the tracts outside (south) of the moraine and but little higher than the valley of Rocky Fork, which lies on the north. As already stated, these gravel hills may belong to the earlier drift sheet instead of this moraine. Both north and south of this portion of the moraine there are rocky hills bearing scarcely any drift, which stand much higher than the moraine. The moraine is, therefore, not so conspicuous a feature as it would be on plane tracts, such as are found in northwestern Ohio or even on those in the adjoining counties, Clinton and Fayette, where there are few rocky hills. In the northwestern part of Highland and in eastern Clinton counties it rises quite abruptly above the flats that border it on the south, in many places a rise of 20 feet being made in as many rods, while the crest of the moraine is 30 to 60 feet above the outer border plain. The Baltimore and Ohio Railroad profile shows at Martinsville a rise of 15 feet in 5 chains and a rise of 62 feet in 52 chains in its passage from the plain to the crest of the moraine. West of Martinsville there is a more gradual rise to the moraine from the outer border plain than that noted east of the village, about 30 feet in a mile being the usual rise in the vicinity of Cuba. North of Clarksville it stands 30 to 50 feet above a plane tract along its outer

border, drained by a small stream known as Flat Fork, and presents an abrupt relief. North from the point where it touches Cæsars Creek, near Harveysburg, it is, as noted above, so closely associated with the correlative Miami moraine as to be distinct only at intervals. Near Xenia the eastern part of the interlobate belt rises boldly above the country west of it, but its altitude there is due, in large part, to the underlying rock, since it lies upon the western edge of the Niagara escarpment. On the Xenia and New Jasper pike, leading eastward from the court-house in Xenia, there is an ascent of about 100 feet in 2 miles, where a summit is reached. A mile or more farther east, and only 40 to 50 feet lower, are outcrops of rock. The inner border relief of the interlobate belt in this vicinity is 30 to 40 feet. In Clinton County the inner border relief is scarcely noticeable except in rare instances; it seldom exceeds 25 feet, and rises for a mile or more to attain this height.

RANGE IN ALTITUDE.

The altitude ranges between 900 and 1,200 feet above tide, being greatest in the vicinity of New Vienna, as shown by the table below:

Altitudes along the Cuba moraine.

	Feet above tide.
Marshall (Ohio Geological Survey)	1,031
Near New Vienna (Baltimore and Ohio Southwestern Railroad)	1,180
Near Martinsville (Baltimore and Ohio Southwestern Railroad)	1,106
Ogden, in valley (Cincinnati and Muskingum Valley Railroad)	901
East of Xenia (aneroid)	1,100

TOPOGRAPHY.

The topography of the moraine is of a gently undulatory type, swells exceeding 10 feet in height not being numerous, while those with a height of 15 to 20 feet are rare. It is undulatory, however, in this slight degree, and thus differs from the plains toward the south, which have extensive tracts so level that the water which falls in the spring often stands on the surface until evaporated by summer drought. The distinctive characters of this moraine are its relief above the flat land which borders it, as was noted above, and its general freedom from silt such as covers the flat land. Were it not for these its classification as a moraine might be doubtful, for in the matter of drift swells it certainly has not a pronouncedly morainic expression; but a consideration of these features and of its connections makes

it evident that it marks a part of the margin of a glacial lobe. The sharp gravel knolls which appear near the line of the moraine in the vicinity of Hillsboro apparently belong to the Illinoian or earlier ice invasion, as already indicated.

In eastern and central Highland County the moraine presents in its outer portion gentle swells of till, 5 to 15 feet in height, each covering areas of 1 to 10 acres or more. Northwest from the Maysville Railway, in survey 2480, small gravelly knolls 10 to 20 feet or more in height abound, several of which are in view from the Cincinnati pike west of Hillsboro. From survey 2480 northward to survey 2351, a distance of about 4 miles, there are no well-defined morainic features.

In northwestern Highland, in Clinton, and in Greene counties there is, aside from the main ridge, which stands 20 to 40 feet above the outer plain, a moderate number of small knolls and gentle swells 10 to 20 feet in height. The majority of these swells are conical, or but slightly elliptical. When elliptical, the trend of the longer axis is usually in line with the moraine, whose trend there is from east of north to west of south.

STRUCTURE AND THICKNESS OF DRIFT.

In the main the drift consists of till, but, like most other moraines and also the intermorainic drift sheets, considerable variation is frequently found within short distances, owing to the presence of local beds of assorted material which occur at various depths. It is from these beds that the wells of the region usually derive their water supply. But in Highland County, in the vicinity of Hillsboro and thence down Rocky Fork, as has been noted, large gravel knolls occur. The gravel in these knolls is largely composed of limestone pebbles, and much of it near Hillsboro is cemented, and in general it has the aged appearance of the earlier drift. It shows strata in various attitudes, but where opened extensively horizontal stratification predominates.

The lower limit of this sheet of drift is in places shown by a buried land surface, having a soil and peaty deposits. The buried soil is found at Marshall, as has been noted by Orton, and many wells reported to the writer in Martinsville and some at Wilmington strike it. It is well exposed along a ravine in the south part of Wilmington, as described below.

The buried soil, wherever noted in Highland and Clinton counties, is

usually but 20 to 25 feet, rarely 40 feet, from the surface, and it is thought to constitute, as a rule, the surface of the older or Illinoian drift sheet. Apparently this slight depth represents the usual thickness of the early Wisconsin drift in this region, for it is not over 25 feet on the moraine at Martinsville and Marshall, and may be even less on the inner plain.

At Martinsville many wells strike considerable vegetal material, wood, soil, etc., at about 20 feet, but occasionally as low as 40 feet. Wells in this village 40 to 45 feet deep do not reach rock. In some wells inflammable gas issues at a depth of from 30 to 40 feet, and is perhaps derived from the vegetal deposits of the drift. The drift there is mainly till, both above and below the buried soil.

Orton has reported that at Marshall 11 out of 20 wells struck a buried soil or vegetal material at slight depth. The drift at this place extends deeper than the horizon of the soil, since wells 25 to 30 feet deep on low ground, as well as those on knolls, fail to reach rock.

Near Wilmington the distance to rock on surfaces having no marked difference in altitude ranges from a mere trace up to 80 feet or more, there being an outcrop of rock just east of the city, while on ground equally low within the city limits 60 feet of drift is not uncommon, and the gas-well boring north of the city, on ground but little higher, penetrates about 80 feet of drift. The late L. B. Welch, of Wilmington, has ascertained that wells in Wilmington, where drift is 60 feet deep, penetrate about equal amounts of older drift and newer, and the older, i. e., that below the buried soil, is drier and much more difficult to penetrate than the newer, probably because of a partial cementation. Excellent exposures of the buried soil are found along Lytles Creek in the south part of Wilmington. The soil is 2 to 6 feet in thickness and of very dark color. It is overlain by 15 or 20 feet of Wisconsin till and underlain by about the same amount of Illinoian till. There is a small amount of white clay resting on the soil, but in most of the exposures the clay was removed before the Wisconsin till was laid down, so that the till commonly rests directly on the soil. The till below the black soil is oxidized to a depth of 10 or 12 feet, below which it is of a blue color. It is on Lytles Creek, a few rods below the place where the buried soil is exposed, that striæ were found beneath the Illinoian drift. They bear S. 32° W., or in about the same direction as the Wisconsin ice movement. As above noted (p. 326), they bear strongly upon the inter-

pretation of the direction in which the Clinton limestone of the "Betty Heidy" quarry was transported.

Welch has found many Devonian fossils in the drift near Wilmington, which accord with the striæ and the Wisconsin moraines in indicating a southwestward movement of the ice sheet, for the principal outcrops of Devonian strata are to the northeast.

Wells in Wilmington also strike a bed containing molluscan shells beneath about 25 feet of till and above the hard till of the Illinoian drift. They were probably in the white clay referred to the Iowan stage. Welch collected a considerable number of these shells, which await identification, though they seem to be largely *Succinea avara.* He also examined exposures of the buried soils and found seeds of *Sagittarius* and the bulrush of northern ponds; also pieces of wood, one of which shows beaver cuttings; and another was thought by him to show evidence of charring by fire. Of these specimens the writer has seen the first-named piece of wood and the collection of shells from below the till. The wood appears to be cedar. The shells are all minute, being scarcely one-eighth inch in diameter, and were in their original matrix of fine silt.

In Greene County there are few deep wells along the moraine, water being usually found at 20 feet or less. The following records of deep wells are the only ones obtained.

At C. W. McDonald's, on the Xenia and Wilmington pike, about 2 miles south of Xenia, a well 52 feet in depth does not reach rock. It was thought by Mr. McDonald to be mainly through till. At a schoolhouse about 1½ miles southwest of Paintersville, on the plain east of the moraine, a well was dug which has the following section, as reported by D. H. Oglesbee, who assisted in digging it:

Section of schoolhouse well near Paintersville, Ohio.

	Feet.
1. Yellow till	8–10
2. Blue till	40
3. Dry sand	10–12
4. Hard, dry clay of bluish color, penetrated	20

The well was abandoned at about 80 feet. Another well made subsequently at the same schoolhouse obtained water at 125 feet, which overflows, but the writer was unable to obtain a detailed section. Oglesbee is of the opinion that it did not reach the bottom of the drift.

BOWLDERS.

There are few bowlders either on the moraine or on the inner border plain, but what is lacking in number is partly made good in size. A gneiss bowlder on the farm of the Clinton County infirmary, about 200 yards south of the Wilmington and New Vienna pike, measures 47 feet in circumference $1\frac{1}{2}$ feet above its base. Its highest point stands 9 feet 8 inches above ground, and it is evidently sunk into the ground to some depth. It has a diameter from north to south of nearly 20 feet, but from east to west it is scarcely 10 feet. It contains a few very coarse crystals of feldspar several inches in diameter, and coarse masses of quartz, but the crystals are generally fine. A short distance south of the crossing of the Midland Railway by the Wilmington and Cuba pike, there is a limestone bowlder 11 or 12 feet long and 6 or 7 feet wide standing about 1 foot above ground. It contains *Favosites* and cyathophylloid corals (species and geological horizon not determined). A number of small bowlders 1 to 2 feet in diameter, mainly granite, were observed between Cowans Creek and Cuba. They are more numerous there than elsewhere on this moraine, but they constitute no serious hindrance to the cultivation of the soil. Nearly all the bowlders observed are well rounded; this is especially true of the smaller ones. Pebbles are generally quite rare on this moraine to a depth of a foot or more, but the moraine has not such a continuous deposit of silt as occurs on the outer border plain.

INNER BORDER PHENOMENA.

In Greene County there is a plane tract between the Cuba moraine and a neighboring later moraine. In Clinton County there is a generally plane surface between these moraines, but just east of Wilmington there is a small drift ridge trending from northwest to southeast. It has a more or less distinct continuation in both directions, but joins the Cuba moraine at the northwest in northwestern Clinton County, and at the southeast a short distance southeast of Wilmington. Its surface is about 30 feet above the tracts east and west of it, where the Washington and Wilmington pike crosses, but as a rule it is scarcely so prominent. Its width where most prominent is less than a mile. The surface of the crest is gently undulatory, with oscillations of 10 to 15 feet, more or less. These undulations, though slight, are in contrast with those of the smoother till tract on

either side, which scarcely exceed 5 feet. In Highland County the inner border district is hilly, but the drift has usually a plane surface; occasional knolls and ridges of small size and limited extent appear.

STRIÆ.

The bearings of the striæ are on the whole in harmony with the distribution of the moraine, since they form a diverging series bearing southward, southwestward, and westward to meet the moraine nearly at right angles. While the majority may have been formed at the Wisconsin invasion, one exposure is certainly of Illinoian age, as indicated above. Observations were made as follows:

1. On the south bluff of Lees Creek, near the top of the hill, 140 to 150 feet above the creek valley. Exposed in a ditch on the west side of the East Monroe and Hillsboro pike, bearing S. 12° W. (magnetic). The rock surface rises rapidly toward the south, affording an excellent surface for the glacier to work upon. The striæ take the form of numerous fine lines.

2. On Bull Run, a tributary of Hardins Creek, in survey 2518, about one-fourth mile east of the Leesburg and New Petersburg pike, bearing S. 9° W. (magnetic). The rock is a hard brown limestone, perhaps siliceous in part. The exposure is in the bed of the stream, and the glaciation consists of shallow grooves one-half inch or more in width, and of fine lines, all having, so far as determined, the same bearing.

3. In the second railway cutting west of Leesburg in a ditch at the side of the track, on brown limestone, bearing S. 18° W. (magnetic). The striæ consist of fine lines, parallel so far as observed. In a cutting between this place and Leesburg the railway has removed layers of rock to a depth of several feet. Mr. Hilliard, of Leesburg, states that he has observed striæ in this cutting bearing west of south. Orton has reported striæ on a hill to the south, the altitude being 75 feet or more above the level of the exposure in the railway cutting.[1]

4. In Clinton County two striated exposures were noted. One is on the Clinton limestone, in the bed of Lytles Creek in the southwest part of Wilmington, bearing S. 32° W. (magnetic).

5. The other is just below the railroad bridge west of Ogden on a low

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[1] Rept. Ohio Geol. Survey, 1870, p. 265.

bench of rock at the west side of the creek bed, bearing S. 37° W. It consists of a multitude of fine lines on a blue fossiliferous limestone of Lower Silurian age.

6. Chamberlin has reported striæ on Andersons Fork southwest of Reesville, bearing S. 45°–56° W.[1]

7. On the east side of the Wilmington and Xenia pike near the top of the north bluff of Cæsars Creek, in Greene County, are several glaciated exposures, bearing S. 40° W. (magnetic).

8. Near New Jasper, Greene County, in Bickett's quarry, south of the Xenia and New Jasper pike, the rock surface is planed to glassy smoothness and covered with striæ, the majority of which bear W. 5° N., but they range from W. 2° N. to W. 20° N. (magnetic). The westward movement was determined by the examination of a cherty prominence in the stone, the east side being the stoss side.

9. At Conklin's quarry, near New Jasper, a short distance east of Bickett's quarry, on the bank of Cæsars Creek, bearing of nearly all the striæ about W. 17° N. This rock, because of its hardness, is not planed down like that in Bickett's quarry. There are many depressions and furrows so striated as to indicate a westward movement, the strongest striation and heaviest planing being on the west side of such furrows as were too deep for the ice to striate to the bottom.

OUTER BORDER PHENOMENA.

The earlier drift and its silt capping having been discussed, it remains only to discuss the fluvial plains. There are two streams, Todds Fork and the East Fork of Little Miami, which lead from the moraine under discussion into the outer border district, and whose valleys were available for the escape of glacial waters at the time the moraine was forming. The East Fork was not examined for evidences of glacial streams, but Todds Fork was found to carry remnants of a gravel terrace which is apparently of the same age as the moraine. At the outer border of the moraine just above Clarksville the terrace is well exhibited, occupying nearly the whole width of a broad valley. Its connection with the moraine is not so close as in certain other streams which the writer has examined within the glaciated district, but this may be due to the fact that the moraine does not fill the valley, but simply dots the slope with scattering knolls.

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[1] Third Ann. Rept. U. S. Geol. Survey, 1883, p. 340.

This much is certain, however, that gravel deposits are rare above the moraine and very abundant below it. The height of the terrace at the border of the moraine is about 30 feet above Todds Fork, and it is about the same at Clarksville. At a railway switch about midway between Clarksville and Hicks station it rises 40 feet or more above the creek. In the vicinity of Hicks station it is 40 to 50 feet, while along the north-flowing portion of the creek, 1 to 1½ miles above its mouth, the terrace stands about 60 feet above the creek. It continues down Little Miami River, being well exposed in the south bluff for 2 miles below Morrow. The descent of the terrace near its head is about the same as that of the creek, 18 to 20 feet per mile, but farther down it is less rapid. From Clarksville to the exposure a mile above the mouth of the creek, its descent is about 130 feet in 10 miles. The fall of the present stream in the same distance is 160 feet.

The Cincinnati and Muskingum Valley Railway has opened a gravel pit in the terrace near its head, about a mile above Clarksville. It exposes 3 or 4 feet of sandy gravel at top, beneath which is gravel with but little sand intermingled, exposed to a depth of about 20 feet. It is horizontally bedded and contains many pebbles 3 to 4 inches in diameter. Much of the gravel is well-rounded local limestone, but Canadian rocks are not rare. At Clarksville a well on the terrace at the Hadley House, 20 feet in depth, did not reach the bottom of the gravel. It was described by Mr. Hadley as containing coarse gravel with pebbles 3 to 4 inches in diameter, thin beds of fine gravel being interbedded with the coarse. Mr. A. W. Thomas has a well on the lot adjoining the Hadley House which reached the bottom of the gravel and entered a blue shale at 20 feet.

At the exposure near the mouth of Todds Fork the upper 20 feet consists of well-rounded gravel containing Canadian as well as local pebbles. Few pebbles exceed 3 inches in diameter, and there is much fine gravel and sand intermixed with the larger pebbles. There is no silty capping here such as occurs near Clarksville. Below the gravel for about 20 feet there is a poorly assorted material in which many slabs of local limestone occur, and beneath this is about 20 feet of blue till. The till apparently fills a narrow gorge in the rock strata, for a few rods up stream from the deposit of blue till limestone strata are exposed which rise to the level of the top of the deposit.

SECTION III. PROBABLE EARLY WISCONSIN DRIFT OF THE GRAND RIVER LOBE.

As indicated in the discussion of the drift border, a portion of the extramorainic drift in eastern Ohio and western Pennsylvania, notably that in Columbiana County, Ohio, and Beaver County, Pa., appears to be as recent as the early Wisconsin, while that in counties to the east seems to be much older, Kansan or pre-Kansan in age. The portion thought to be of early Wisconsin age extends only a short distance, nowhere more than 10 miles, beyond the strong outer moraine of late Wisconsin age. It is rarely aggregated in knolls or ridges, thus differing markedly from the hummocky surface of that moraine. It fills the valleys and lowlands to considerable depth, but on ridges and hills it is represented only by scattering pebbles and occasional thin deposits of till. The till is often present in considerable amount on the north side of ridges nearly to the crest, while the south side at similar altitudes is almost destitute of drift. The till is of a clayey constitution, like that of the early Wisconsin farther west.

The chief reason for assigning this part of the extramorainic drift to a later stage than the old drift farther east is found in its comparative freshness. It is but little more weathered than the late Wisconsin drift of the neighboring moraine. A response with acid can usually be obtained at a depth of but 5 or 6 feet The bowlders also are but little more weathered than those on the surface of the late Wisconsin moraine. They are strikingly in contrast with the rotten and deeply weathered bowlders and pebbles which characterize the old drift of northwestern Pennsylvania.

The grounds for separating this extramorainic drift from the late Wisconsin are perhaps open to question. It has impressed the writer, and also Professor Chamberlin, as somewhat more weathered than that of the neighboring late Wisconsin moraines. The fact that it is so strikingly different in topography has also been considered a matter of some consequence. It also seems natural that this lobe, as well as the Scioto and Miami lobes, should have extended farther in the early Wisconsin than in the late Wisconsin stage. But the reference to the early Wisconsin is only provisional. This drift may yet prove to be the product of an advance but little earlier than that which formed the bulky late Wisconsin moraine.

CHAPTER XI.

THE INTERVAL BETWEEN THE EARLY AND LATE WISCONSIN DRIFT.

The Hartwell-Cuba moraine and its associated sheet of drift, and the morainic tracts in the reentrant between the Scioto and Miami lobes, appear to be the only outlying representatives of the early Wisconsin drift in this region, the remainder of the series being concealed beneath the moraines and drift sheets which are here referred to the late Wisconsin series. The evidence of an interval between the deposition of the early Wisconsin drift and the formation of the outer moraine of the late Wisconsin series is well shown in the elevated land lying between the Miami and Scioto lobes, where, as above noted, the outer moraine of the Miami lobe and the outwash gravel associated with it had been trenched by streams prior to the formation of the neighboring late Wisconsin moraines of the Miami and Scioto lobes. Professor Chamberlin noted this channeling and interpreted it as evidence of an interval while making a reconnaissance of western Ohio in 1883, and the writer gave it further attention a few years later. The cutting of the broad valley of Mad River, about 2 miles in average width and 25 to 50 feet in depth, was referred by Chamberlin to this interval, as were also similar channels of its tributaries. In the late Wisconsin stage the ice came down about to the valley of Mad River on the west and covered the upper portion of the western tributaries. The sheet of drift deposited at this later advance only partially fills some of the tributaries, but its knolls dot the slopes and bottoms of the interglacial channels, thus repeating the phenomena of the early Wisconsin moraine in valleys of the Whitewater system noted above (p. 306).

On the east side of the Mad River drainage basin there are similar phenomena associated with the outer late Wisconsin moraine of the Scioto lobe. This moraine descends into valleys cut in the early Wisconsin drif of that region. The details are given in connection with the discussion of that moraine (pp. 382 et seq.).

It should perhaps be stated that Mad River and its tributaries do not follow to any great degree preglacial lines, the concealed rock surface, if we may judge from well data, being nearly as elevated along the valleys as beneath bordering uplands. The evidence appears decisive that the valleys are interglacial and not preglacial.

The evidence of an interval is less striking on the south and west border of the Miami lobe than that on the east, just noted. On the Great Miami, the valley gravels leading away from the later sheet of drift have filled its channels about to the level of the early Wisconsin terraces. On some of the western tributaries of the Great Miami the gravels of the later invasion lie in trenches cut into the drift of the early Wisconsin, but the trenching is not conspicuous, probably because of the small size of the interglacial streams and their moderate rate of fall. In Whitewater Valley the gravel of the late Wisconsin has been built up about to the level of the early Wisconsin gravel, rendering it difficult to separate the two. On the whole, the interval between the early and late Wisconsin appears much briefer than the Sangamon interglacial stage, and somewhat briefer than the Peorian.

The difference in the erosion features of the early Wisconsin sheet and those of the outer moraine of the late Wisconsin appear no more striking than between the Shelbyville and the Valparaiso moraines of the Illinois glacial lobe; indeed, the difference in the outwash seems scarcely so striking. It is, however, such a difference as would naturally be found in passing from the outer part of the early Wisconsin to the outer part of the late Wisconsin in Illinois, and is greater than is found in that State in passing from the northern or later part of the early Wisconsin to the southern or outer part of the late Wisconsin. From this it is inferred that the Hartwell-Cuba moraine is a correlative of either the Bloomington or the Shelbyville moraine of the Illinois lobe, rather than the Marseilles. However, the precise correlation of this moraine with a moraine of the Illinois lobe has not been attempted.

CHAPTER XII.

THE MAIN MORAINIC SYSTEM OF THE LATE WISCONSIN STAGE.

SECTION I. IN THE MIAMI LOBE.

THE MORAINES.

GENERAL STATEMENT.

Under this name is discussed a series of moraines whose members in part coalesce and therefore are more easily described together than separately. This system where best differentiated comprises three moraines. Of these the outer two were examined by Chamberlin, and are briefly described in his paper in the Third Annual Report.[1] The third or inner one lies but a few miles north from the second, and is distinct from it only in the midst of the terminal loop. The entire system, including the narrow plains lying between the moraines, has nowhere a width exceeding 18 miles, and where the members are closely associated the width is reduced to 10 miles or less.

DISTRIBUTION.

At the head of the reentrant angle near Bellefontaine, Ohio, this morainic system connects with the correlative system of the Scioto glacial lobe. The eastern limb follows and constitutes the western bluff of Mad River from the source of the stream east of Bellefontaine, southward nearly to the latitude of Urbana, the several members being united into a single great belt. It then leaves the river to the east for a few miles and passes southwestward through New Carlisle, near which it begins to separate into distinct members. The outer member crosses Mad River near its mouth and follows nearly the east bluff of the Great Miami from Dayton about to Franklin. Here it swings westward, crossing the Great Miami Valley near Carlisle, and passing south of Germantown and north of West Elkton, enters the valley of Sevenmile Creek at Camden. It then swings abruptly northward, passing near Sugar Valley, West Florence, and Westville, striking the State line between New Paris, Ohio, and Richmond, Ind. Near the State line it

[1] Terminal moraine of the second Glacial epoch, by T. C. Chamberlin: Third Ann. Rept. U. S. Geol. Survey, pp. 334–335.

is joined by the other members of the system. In Indiana the united belt passes north of west across northern Wayne and southern Randolph counties into northeastern Henry County, where it connects with the correlative moraine of the East White lobe.

The outer member is quite distinct around the southern end of the loop from near Dayton to the State line and has a width of 2 to 3 miles. Throughout the remainder of its course it is more closely associated with the later members, but it does not appear to be overridden by the later ones except in the extreme northern portion of the eastern limb, and possibly in the reentrant angle between the Miami and East White lobes, in Henry County, Ind.

The middle member is clearly recognized throughout its entire length by the remarkably large number of bowlders which it carries. It lies in the midst of the morainic system, passing from the head of Mad River (east of Bellefontaine) southwestward near Spring Hills, Mosquito Lake, St. Paris, Christiansburg, and West Charlestown, and crossing the Miami River just above Dayton. It then makes a gentle curve around the southern end of the loop, passing about 3 miles north of Germantown, and touching the villages of Farmersville, Enterprise, and West Alexandria, and the northern part of the city of Eaton. From Eaton it follows the northeast side of Sevenmile Creek northward to its source near Ebenezer, and continues northwest past Brinley and Braffettsville, coming to the State line just north of the village of Whitewater, Ind. In Indiana it passes through Bethel and touches Arba, lying mainly south of the village. It crosses the Grand Rapids and Indiana Railway 2 to 4 miles south of Lynn, and comes to the Big Four Railway near Bloomingsport and continues near the line of that railway to Losantville, then passes north into Henry County, connecting near Blountsville with the correlative moraine of the East White lobe. The usual width of this member where distinct is 2 miles or less.

The inner member is not so strong as the others and forms a distinct belt for only a few miles in the point of the terminal loop. Its inner border is usually sufficiently in contrast with the plains north of it to admit of mapping, but in places it passes into them by insensible gradations. The position of this inner border may be indicated approximately by lines connecting the following towns: Degraff, Quincy, Palestine, Fletcher, Troy, Harrisburg, Pyrmont, Sonora, Ithaca, and Fort Jefferson, Ohio; and

Spartanburg, Snowhill, Huntsville, and Windsor, Ind. The width of the inner member, where distinct, is 2 to 3 miles, being greater than that of the middle member.

RELIEF.

Throughout the terminal loop the outer member of the system has a general relief of 20 to 30 feet, while its highest points rise to a height of 50 feet or more above the outer border district. It can scarcely be entered at any point from the outer border district without making a perceptible, and throughout much of the border an abrupt, rise. In the reentrant portions the relief is less easily determined, since the moraine breaks up into sharp knolls more than in the terminal loop. On the inner border the rise into the moraine is somewhat less and is also more gradual than on the outer border.

The middle and inner members of this system have a relief above bordering districts nearly as great as that of the outer member, but the rise is less abrupt; they are consequently less conspicuous topographic features.

RANGE IN ALTITUDE.

The eastern limb of this morainic system has a range in altitude of about 850 feet, and the western limb nearly 400 feet. The rock surface has equally great range, as may be seen by the following table of altitudes:

Table of altitudes along the moraine.

Station.	Drift surface (above tide).	Rock surface (above tide).
	Feet.	*Feet.*
Uplands east of Bellefontaine	1,350–1,540	1,150–1,400 ±
Hogue Summit	1,540	1,150
West Liberty, in valley	1,100	883
Spring Hills, on uplands	*a* 1,150	760–1,000 ±
Mosquito Lake, in valley	*a* 1,100	?
St. Paris, on uplands	1,238	700–870
Little Mountain, near St. Paris	1,326	?
New Carlisle, in valley	883–915	?
Osborne, in valley	830	625
Uplands in east part of Dayton	1,000–1,100	1,000 ±
Dayton, in valley	750	525 ±
Carlisle, in valley	696	500 ±
Uplands south of Germantown	*a* 1,000	950 ±
Camden, in valley	839	658
Uplands in northwest Preble County, Ohio, and in Wayne and Randolph counties, Ind	1,175–1,225	1,050–1,100

a Barometric.

TOPOGRAPHY.

The outer member of this morainic system has, on the whole, stronger expression than the middle and inner members, but it is less plentifully supplied with bowlders. The knolls and ridges in each of the members are of characteristic morainic types.

Since the eastern limb is not clearly differentiated into distinct members it may be discussed as a unit. At its northern end it is strongly morainic throughout its entire width, consisting of sharp knolls and winding ridges 10 to 50 feet in height, thickly strewn with bowlders and enclosing basins 5 to 20 feet in depth. The Hogue Summit, 2 miles east of Bellefontaine, which is reported to be the highest point in Ohio (1,540 feet above tide),[1] is a morainic knoll having a height of about 40 feet and covering 8 or 10 acres. Other knolls in that vicinity rise to within 20 or 25 feet of the same altitude.

In southern Logan County and in Champaign, Clark, and Miami counties the features of the moraine are extremely variable. In its eastern or outer part are occasional clusters of very sharp and prominent knolls 30 to 75 feet in height, illustrations of which may be seen 3 to 4 miles northwest of West Liberty and in the vicinity of Spring Hills, also west of St. Paris and in Honey Creek Valley west of New Carlisle; but much of this eastern part is characterized by a subdued morainic topography, with knolls and ridges only 10 or 15 feet in height, among which shallow basins are inclosed, nearly the entire surface being undulatory. In the western or inner part of the eastern limb a somewhat different topography appears, knolls 10 to 25 feet in height dotting the surface of an otherwise nearly plane tract, and occupying but a small fraction of it. Basins are rare compared with the outer part of the moraine. Bowlders are very abundant both on the knolls and the plane-surfaced tracts.

Where the moraine-headed terraces or gravel plains connect with the moraine, as in Mad River Valley near West Liberty, and again east of New Carlisle, on Glade and Muddy creeks near Northville, and on Nettle Creek near Millerstown, the morainic knolls come down to the gravel plains and occasionally occur like islands on them. The latter statement is especially true of the district east of New Carlisle, where morainic knolls and ridges

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[1] See Geology of Ohio, Vol. III, p. 482.

20 to 40 feet high occur out to distances of a mile or more in the gravel plain. They appear to have been built up at the time the gravel plain was occupied by glacial waters, having been no evidence found that they were cut into by glacial streams. However, the materials comprising the knolls are such as are subject to landslides, creeping, and rapid erosion, and it has been so long since the gravel plains were occupied by streams that erosion marks may have been obliterated.

The several members of the morainic system are sufficiently distinct around the southern end of the loop to make it advisable to discuss them separately. The portion of the outer member lying south of Mad River, along the east bluff of the Great Miami, has greater strength than is displayed elsewhere by this member. There is in places a well-defined ridging in a north-northeast to south-southwest direction, i. e., in line with the trend of the moraine, the ridges succeeding each other at intervals of one-half mile or more and standing 15 to 30 feet above the intervening tracts. One ridge was noted, however, in which the trend was nearly east to west. It lies 2½ miles north of Centerville, is about a mile in length and one-fourth mile in width. Its highest points reach an altitude of 50 to 60 feet above the bordering district. From this ridge northward to Mad River Valley the moraine has sharper knolls than it has toward the south, there being many whose height is 40 to 50 feet and whose slopes are but 20 to 30 rods in length. The outer border of the moraine in this portion of the belt is somewhat irregular, and patchy developments of morainic topography occur for a mile or more east of the main ridges.

In the Great Miami Valley this moraine is very feebly developed, but in the vicinity of Carlisle low ridges occur, among which are basins and irregular depressions.

On the uplands between the Great Miami and Sevenmile Creek the moraine consists of a broad basement ridge standing 20 to 40 feet above the outer border tract and having a width of 1½ to 3 miles. On its crest and slopes are minor ridges and knolls 10 or 15 feet in height, among which sags and irregular depressions are inclosed.

In Sevenmile Creek Valley the moraine is only feebly developed, but where the moraine crosses the valley a decided change in structure occurs, there being a well-defined gravel plain south of the moraine, while north of it there is scarcely any gravel, the valley of the creek being cut in till depos-

its. From Sevenmile Creek northwestward into Indiana the moraine presents a main ridge standing 15 to 30 feet above the outer border plain, on whose crest and slopes there are small knolls and ridges. The outer portion of the moraine has a uniformly undulatory surface, while the inner slope has clusters of knolls around which the surface is nearly plane.

In northern Wayne and northeastern Henry counties, Indiana, groups of knolls occur, but at least half the surface is very gently undulating. The highest knolls are only about 25 feet in height, but some of them appear prominent because of very abrupt slopes.

Returning to the Great Miami Valley and taking up the middle member, we find it crossing the stream just above Dayton; indeed, its outer border extends into the northwest portion of the city, known as Dayton View. It is well developed near the mouth of Stillwater River, where it consists of gravelly knolls rising to a height of 25 to 40 feet above the river bottoms. The moraine is feebly developed on the uplands between the Stillwater and Miami south of Chambersburg, consisting of low swells 10 feet or less in height, on which bowlders are numerous. On the highlands west of Dayton, in the vicinity of the Soldiers' Home, the moraine has very feeble development, but southwest of these highlands, in the lowland tract south of Liberty, it is well defined, with knolls closely aggregated and thickly strewn with bowlders. The height of the knolls is slight, being but 10 or 15 feet. From this lowland tract northwestward to Ebenezer (near the State line) the moraine has scarcely any knolls exceeding 15 feet in height, and but few have sharp contour. The largest and sharpest knolls observed is a group 3 miles northwest of Eaton, which contain knolls 20 feet in height. Along the outer border are many bowlders, but the topography there is often less sharply morainic than it is a mile or so north of the bowlder belt. For several miles east of the State line and throughout much of its course in Indiana this member has a strong expression, containing knolls 25 to 30 feet in height, among which are basins and irregular depressions, the surface being thickly strewn with bowlders. Its expression is stronger than the portion of the outer member adjacent to it on the south

The inner member of this morainic system is represented in eastern Indiana and western Ohio by irregularly grouped drift knolls of sharp contour, separated by wide stretches of nearly plane-surfaced drift, all liberally strewn with bowlders, though not in such numbers as the middle member.

It is very strongly developed along the valleys also, and since these valleys trend nearly at right angles with the general course of the moraine they present the appearance of spurs leading northward from the moraine.

The most conspicuous of these valley belts noted leads from New Madison northward past Fort Jefferson nearly to Greenville. It includes gravel ridges which have the outline of eskers, but they are interrupted at frequent intervals and replaced by sharp morainic knolls; consequently it seems legitimate to consider them as part of the moraine. The highest knolls and ridges rise 50 to 60 feet above the bordering low ground, but the majority are but 15 to 25 feet in height. The topography from this valley-morainic belt eastward is markedly smoother than it is to the westward, much of it being nearly level. In this eastern district basins are usually numerous. They are small, being but 3 to 6 feet in depth, and occupy only an acre or so each. A short distance east of Fort Jefferson the inner border of the moraine turns abruptly southward and follows Millers Fork of Twin Creek, passing through Ithaca and just east of West Sonora and Euphemia. This portion of the moraine contains only low swells 10 feet or less in height, but its surface is all more or less undulatory. Near Euphemia the moraine leaves Twin Creek and bears eastward past Pyrmont and Air Hill, having in this portion of its course numerous swells 8 to 10 feet in height, which, though low as compared with those in some portions of the moraine, present a sufficiently strong contrast to the flat tracts on the north to make it easily traceable. From Air Hill the moraine passes northeastward, crossing Stillwater River near Little York. It consists mainly of low swells 8 to 10 feet in height, but on the west bluff of Stillwater River, about a mile northeast of Taylorsburg, a chain of sharp gravelly knolls and ridges occurs, whose highest points stand 30 to 40 feet above the bordering portions of the moraine. The chain trends with the moraine in a northeast-southwest course. In Stillwater Valley there is, near Little York, an undulatory lowland standing about 70 feet above the river, on which a slight capping of till and numerous bowlders occur, with heavy beds of gravel beneath.

On the uplands between Stillwater and the Great Miami the moraine has feeble expression, with swells only 5 to 10 feet high, but is very liberally strewn with bowlders, and the bowlders also abound northward over the bordering plains. In the Great Miami Valley, just below Tippe-

canoe, there are sharp, gravelly knolls and ridges varying from 10 feet up to 40 or 50 feet in height.

From the Miami River northward this inner member has been described as a portion of the eastern limb of the morainic system.

THICKNESS OF THE DRIFT.

In the eastern limb of this morainic system the thickness of the drift has a known range from a mere trace up to 530 feet, with an average of probably 200 feet. The thickness on the uplands is greater in Champaign and Logan counties than farther south. The rock surface is much more uneven than the drift surface, the effect of the drift being to fill up the valleys and lowlands to about the level of the preglacial ridges.

The greatest amount of drift yet penetrated in Ohio is found in an attempted gas-well boring at St. Paris, where, after penetrating to a depth of 530 feet, the well was abandoned without reaching the rock. Within 3 miles south of this well, and at about the same altitude as its mouth, a limestone quarry has been opened. The thickness of drift in the gas-well borings at De Graff ranges from 33 to 300 feet, and at Bellefontaine from a thin coating up to 150 feet.

In the Great Miami Valley there may be a continuous deep channel, though it must be narrow, since the river in places has a rock bed, and rock is near the surface throughout much of the valley bottom. The drift in this valley has the following ascertained thickness: Near Piqua, 170 feet; at Troy, 133 feet; at Dayton, 247 feet; at Miamisburg, 181 feet; and at Hamilton, 210 feet There may be points in the valley where it is even thicker than at Dayton.

On the uplands, between the Great Miami and Sevenmile Creek, the thickness is usually between 25 and 50 feet, but in the valley of Sevenmile Creek a boring at Camden shows 180 feet, and borings near Eaton show 75 to 80 feet of drift. Between Sevenmile Creek and the State line the thickness on the uplands ranges from 30 or 40 feet up to 100 feet or more. In eastern Indiana the thickness ranges from 50 feet or less up to fully 250 feet, with an average thickness of 100 feet or more.

What proportion of this drift was deposited previous to the formation of the morainic system under discussion is difficult to estimate, there being, so far as known, no widespread, well-defined soil or weathered zone separating the late Wisconsin drift from the early Wisconsin. Indeed, very few

instances of buried soils have come to notice in this region. A comparison of the thickness of the drift in the district lying outside (south) of the moraines with that covered by them, leads to the conclusion that at least one-half the drift was previously deposited. This constitutes probably the most reliable method of making an estimate. It must, however, be considered a rude approximation, for it is probable that the ice sheet gathered up and redeposited a portion of the drift that it overrode.

STRUCTURE OF THE DRIFT.

The portions of the moraine characterized by a gently ridged or a swell-and-sag topography contain much more till than assorted material, while the sharply ridged tracts and the prominent knolls, so far as opportunity for examination has been afforded, contain a preponderance of assorted material. However, there are, on the gently undulating till tracts, numerous places where gravel appears at the surface both in the knolls and the intervening depressions, while wells indicate that beds of assorted material are interstratified with or deposited in pockets within the till. In the sharp gravelly ridges and knolls the presence of till is not uncommon and it sometimes constitutes a considerable part of the material. While, therefore, the structure admits of division into two classes, there appear numerous abrupt changes in structure such as are characteristic of morainic deposits.

An interesting section of a sharp gravel knoll on an elevated portion of the moraine may be seen $1\frac{1}{2}$ miles southwest of St. Paris. The knoll is elongated in an east-northeast to west-southwest direction and was originally very abrupt at its eastern end, rising within 10 to 15 rods to a height of 75 feet, while toward the west it had a gradual slope. The excavation began in the eastern end and has been carried past the highest part of the knoll, leaving only the western slope. The portion removed contained considerable well assorted sand, gravel, and cobble, but the portion remaining presents an interesting combination of beds, there being deposits of cobble, gravel, and till, intergrading with each other, which are curiously disturbed and contorted in their bedding. The gradual slope on the west side of the knoll forbids the supposition that the beds owe their disturbance and contortions to recent landslides, and leaves it probable that their form and position are due to the molding and pressure exerted by the ice sheet.

Sections of lowland gravel knolls may be seen in the vicinity of New

Carlisle, where an old valley, probably interglacial, is partially filled by the moraine. Near the railway station in New Carlisle there is a gravel pit in which no till appears. The gravel is in various positions—oblique, arching, and horizontal—and varies greatly in coarseness within short distances. Southeast of the station there is a cutting in which gravel and cobble appear near the top, beneath which is a yellow till 10 or 12 feet in depth, and beneath this blue till. The gravel and cobble increase in thickness in passing northwestward, owing to the dropping off of the till. It seems probable that the till belongs to an earlier ice advance than that which produced the gravelly hillocks that cap it, presumably the early Wisconsin. West of New Carlisle there are extensive excavations showing a large preponderance of assorted material in oblique and arching as well as horizontal attitudes. In one instance the knoll is capped by till and bowlders, while the nucleus is of assorted material.

A good exposure of the structure of nearly plane-surfaced upland drift appears at the Beavertown quarries 3 to 4 miles southeast of Dayton. There is being removed here about 20 feet of drift, consisting of an almost continuous capping of yellow till 5 to 10 feet in thickness, beneath which are deposits of poorly assorted gravel and sand horizontally bedded. In places these gravelly deposits reach to the limestone, but fully as often a thin bed of till intervenes. The surface of this lower till is uneven, and the gravel rests unconformably upon it. The lower beds of gravel being horizontal, are shut off where the till rises above their level. This break between the lower till and the overlying deposits may indicate a lapse of considerable time between their depositions, though it is not known but that the erosion of the surface of the lower till was rapidly accomplished by the same streams which deposited the overlying gravel and sand.

A series of interesting sections of plane-surfaced lowland till appear along Twin Creek in the vicinity of Germantown, in a district lying between the outer and middle members of this morainic system. These are of especial interest, since in one locality a peat bed outcrops beneath the till. Attention was first called to the exposures just below (east of) Germantown in 1870, by Orton, who gave at that time an account of the deposits of peat beneath the till.[1] More recently Wright[2] has called attention to the same deposits and added some interesting observations on the occurrence of sheets of till that perhaps mark successive advances and retreats of the

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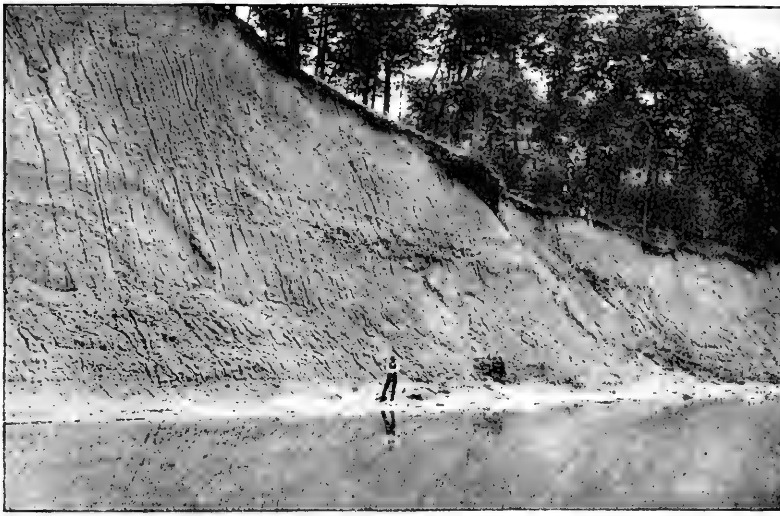
[1] Am. Jour. Sci., 2d series, Vol. L, 1870, pp. 54–57. [2] Bull. U. S. Geol. Survey No. 58, 1890, pp. 96–98.

ice sheet, and has published a photograph showing the section of drift overlying the peat, which is here reproduced (Pl. XIV, *A*). In this section the peat is greatly concealed by talus from the till, but is exposed in one place up to a level several feet above the stream. Among other interesting facts, Orton called attention to the occurrence of cedar berries and fragments of coniferous wood in the peat and of undecomposed sphagnous mosses, grasses, and sedges in its uppermost layers. Beneath the peat is a gravelly deposit, in view only at the eastern or right end of the exposure, and there it is in beds which dip westward at an angle of about 30°, soon passing with the peat below the level of the creek bed. Wright remarks, concerning this deposit, that "the appearance is that of a saucer-shaped deposit of peat, such as would form in a kettle hole, and which was subsequently filled and covered over with the advance of the glacier."

At the time of the writer's visit, in 1889, no exposure of the underlying gravel could be found, and no further data concerning it can be given than appear in the reports by Orton and by Wright. It is not evident from these descriptions whether the gravel beneath the peat is of glacial origin, though there appears to be no reason for doubting that it is, and Wright evidently so considers it. The peat appears to be in situ, since its layers are undisturbed and have a continuous outcrop for about 75 yards. It seems scarcely probable that so large a mass would suffer removal and deposition by the ice sheet without being in a more disturbed or fragmentary condition. The drift deposits resting on the peat have a thickness of nearly 100 feet and are well exposed by the undermining action of the stream. The drift presents a peculiar variation in color and also abrupt variations in structure. The exposure is nearly one-fourth of a mile in length and extends about an eighth of a mile west from the point where the peat disappears. Near its western end the following series of beds are exposed:

Section of Twin Creek Bluff, near Germantown, Ohio.

	Feet.
Yellow till	8–10
Blue till, lens-shaped in outcrop, disappearing in either direction within a few rods	0–6
Yellow till	6–8
Blue till	12–15
Yellow till, local, soon passing horizontally into blue till	5–6
Blue till	10–12
Yellow till, local, soon replaced by sand and gravel	3–4
Sand and gravel	10–12
Creek bed, gravelly.	
Total, about	70



A. SECTION OF PEAT AND TILL NEAR GERMANTOWN, OHIO.

B. SECTION SHOWING WOOD INCLUDED IN TILL, 1 MILE SOUTH OF OXFORD, OHIO.

Just west of this exposure is a partial one in which gravel extends from the creek bed up to a height of nearly 40 feet, a portion of the gravel being cemented. Passing eastward, about an eighth of a mile to the place where the peat comes to view, there is a nearly solid bed of till 95 feet in height without the alternations of yellow and blue color seen in the western end of the exposure. There is at the top of the bluff 10 to 15 feet of yellow till. The remainder of the section is blue till, with the exception of occasional pockets or thin beds of gravel, a few inches, or at most 3 or 4 feet in thickness. Between this point and the western end of the exposure there are places where much gravel appears. The whole exposure is subject therefore to abrupt horizontal changes, and a description which will apply to one place may not apply to another 10 rods distant, the only constant bed observed being the capping of yellow till at the top of the bluff.

The cause of the occurrence of yellow till at several horizons is difficult to determine, especially since it is confined to a very small part of the exposure. Possibly the till was of a yellow color when deposited. There may have been four distinct ice advances, as suggested by Professor Wright, each bringing in blue till, which became oxidized at the surface, forming the yellow till. The occurrence of four such series or successions of beds in one part of the exposure and but one series in the other may perhaps be due to an accident resulting in the preservation in one place and removal in another of the yellow or oxidized portions of the earlier depositions. It seems quite as probable, however, that the oxidized portions of the till were caused by percolating waters which followed lines where the till happened to be most pervious.

Above Germantown, along Twin Creek, there are other extensive exposures of the drift which show in places a double series of yellow and blue tills, but nowhere else within the entire district under discussion have four successive series been found.

In the case of the peat at the base of the till near Germantown, there seems good reason for believing that it indicates the lapse of a considerable interval of deglaciation. Whether the interval preceded the formation of the early Wisconsin moraine or succeeded it remains to be determined. Orton calls attention [1] to the occurrence of soil at considerable depth in wells in this vicinity, showing that remnants of an old buried surface are not uncommon.

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[1] Rept. Geol. Survey Ohio, 1869, Geology of Montgomery Co., pp. 165–167.

The presence of buried oxidized tills and of sand and gravel deposits between till sheets can not, in the writer's opinion, be cited as demonstrative evidence of retreats and advances of the ice sheet unless accompanied by other and more certain lines of evidence, such as peat beds or soils, leached and eroded surfaces, etc. Their occurrence seems rather a problem demanding investigation than a line of evidence from which conclusions can be drawn.

In the western limb of the moraine no extensive natural exposures were observed; we pass, therefore, to the data afforded by well records, beginning the discussion at the northern end of the eastern limb of the morainic loop.

The following record of drift, penetrated in a gas-well boring at the Buckeye Portland Cement Works, near Harper, was furnished by G. W. Bartholomew, jr., treasurer of the company. The well mouth is about 1,260 feet above tide, and the well is situated in the valley of Rush Creek, about 1 mile east of Harper station, at the edge of a marshy tract.

Section of drift beds in a gas boring near Harper, Ohio.

	Feet.
Blue clay	15
Gravel (water stood 7 feet below well mouth)	20
Clay	20
Gravel (water stood 15 feet above well mouth)	10
Clay	20
Gravel (water stood 17 feet above well mouth)	95
Yellowish and brown bowlder clay (probably Illinoian)	65
Helderberg limestone at 245 feet.	

Bartholomew reports that a well for water was bored about a mile north of this gas well. It penetrated 100 feet of drift before reaching a water-bearing gravel, thus presenting a marked contrast to the upper 100 feet in the gas well. On the bordering uplands the rock surface reaches in places an altitude of 1,400 feet, or nearly 500 feet above the rock floor in Rush Creek Valley.

A well for water at Benjamin Easton's, near the Hogue Summit, east of Bellefontaine, is reported by the driller, J. A. Hartzler, of Bellefontaine, to have penetrated 350 feet of drift, of which the upper 60 or 70 feet is largely gravel, while the remainder is mainly blue till. No Devonian shale was encountered, the first rock being the Helderberg limestone. The altitude of the well mouth is about 50 feet below that of the Hogue Summit, or 1,490 feet above tide. The well was not a success in the yield of water,

and only a short piece of projecting pipe marks its position; but it is of much scientific value in that it indicates that the supposed highest point in Ohio is in a region of very heavy drift deposits, and, since it carries an unusual amount of drift, owes its great height only in part to a high altitude of the rock surface.

Hartzler reports other wells in the neighborhood of Bellefontaine which show large amounts of drift, as follows: At Mr. Easton's, 1½ miles south of Bellefontaine, a well 140 feet deep penetrated ordinary till about 120 feet, then a red clay, very hard and dry, 20 feet, beneath which water-bearing sand was struck, from which bits of wood were pumped up. In a well on Charles Scott's farm, on the hill north of West Liberty, wood was encountered in a red, sandy clay at a depth of 160 to 170 feet, after a thick bed of blue till had been passed through. The well terminates in gravel at a depth of 200 feet. Just above the water-bearing gravel there is a bed of blue bowlder clay. The altitude of the well mouth is about 1,200 feet. A well at Mrs. Dille's, 4 miles south of Bellefontaine, penetrated 93 feet of drift, mainly gravel, and at that depth entered limestone. A well near Spring Hill, on the farm of Daniel S. Corey, penetrated 390 feet of drift, the greatest amount yet found by Hartzler. The following succession of beds was passed through, as given from memory, but the exact thickness of each bed was not remembered:

Section of Corey well near Spring Hill, Ohio.

	Feet.
Gravel, about	90
Blue till with thin beds of assorted material	200
Red clay (at about 320–340 feet)	20
Blue clay	30–40
Green and red clays resting on the rock.	

The wells in Bellefontaine made in prospecting for natural gas have the following amounts of drift, as reported by Dr. Covington, of that city:

Thickness of drift in Bellefontaine gas borings.

	Feet.
Carter's well, three-fourths mile south of court-house	95
Well on Huntsville road, 1 mile northwest of court-house	50
Well west of railway station	150

In the vicinity of the Ludlow survey line, at a distance of 4 or 5 miles south from Bellefontaine, the rock rises to the surface in prominent portions of the uplands, and it also lies near the surface just north of Bellefontaine at altitudes much above the level of the railway station.

Three wells in Degraff, made in prospecting for gas, have the following amounts of drift:

Thickness of drift in Degraff gas borings.

	Feet.
Lippincott well, one-half mile north of railway station	300
Harris well, one-fourth mile west of railway station	33
Reid well, one-half mile farther west	86

A well for water at H. A. Hill's, 2 miles north of West Liberty, penetrated 18 or 20 feet of till and then entered gravel, in which it continued to a depth of 87 feet. Several other wells near Hill's have a depth of 60 feet or more and do not strike rock.

At John Newell's, in section 10, Union Township, about 3 miles northwest of West Liberty, a well penetrated about 150 feet of drift, nearly all till, and struck no rock. In West Liberty a prospect drilling for gas penetrated 216 feet of drift, striking rock at an altitude less than 900 feet above tide.

At St. Paris a gas-well boring was attempted near the station at an altitude about 1,216 feet above tide, which penetrated 530 feet of drift, and was abandoned without reaching rock. Orton has called attention[1] to the occurrence of a tough brown clay at a depth of 360 feet, the section above that depth being mainly blue and gray tills. At 400 feet gravel was struck in which, as reported to Orton, wood, bark, and fragments of mussel shells were struck. Dr. J. J. Musson, a resident of St. Paris, informed the writer that the report that mussel shells were pumped out from this depth seems based only on the Paleozoic fossils which are found in some of the pebbles. Fragments of the wood were preserved and pronounced to be red cedar. Beneath the gravel which contained this wood quicksand of some depth was passed through, but the well terminated in bowlder clay. Orton suggested that this deeply filled valley was the ancient channel of the Miami River, but the exact course of the valley southward from this point remains undetermined. It is also doubtful if it had a southward discharge, there being some evidence of a channel leading northwestward into Indiana. Toward the north a valley of similar depth has been struck at Port Jefferson, Anna, New Bremen, and near St. Marys, and it has recently been traced by Bownocker into Indiana.[2]

No surface indications of the position of the channel are to be found,

[1] Geology of Ohio, Vol. VI, 1888, p. 277. [2] Am. Geologist, Vol. XXIII, 1899, p. 182.

for the drift has filled that whole region to a level above the tops of the highest limestone ridges of the preglacial divides. The data concerning the wells referred to are presented later, in connection with the discussion of the region in which they occur. A well in St. Paris, 80 rods northwest of the one reported above, struck rock at 370 feet, but no data concerning the character of the drift were obtained.

At Troy the drift has a known variation from 50 to 133 feet in thickness. At New Carlisle a large amount of drift was penetrated, but the writer was unable to learn its exact thickness and structure. The uplands north of New Carlisle, for a distance of 10 miles or more, are thinly coated with drift, and so also are those south of this village between Honey Creek and Mad River. West of the Miami River, also, the drift is thin from Troy southward to Dayton. Some of the wells west of Tippecanoe on the uplands strike a dark-colored clay, perhaps a soil, just above the rock. In Tippecanoe water wells penetrate 30 feet or more of till. Below Tippecanoe, in the vicinity of Tadmor, there are lowland tracts along the Miami River, where tributaries enter from the uplands, in which 50 to 75 feet of till is exposed.

The greater part of the city of Dayton stands on a gravel plain, but in the portion west of the Miami, known as Dayton View, the drift has an undulating surface, and, though mainly composed of gravel, has a capping of till thickly set with bowlders. A gas-well boring near the corner of First and Findlay streets penetrated 247 feet of drift, mainly till. A well on the waterworks grounds near Mad River, 225 feet in depth, did not reach the rock. This penetrated clayey deposits (probably alluvial) for about 50 feet, beneath which depth the drift was mainly gravel. The supply of water for the city is obtained from a series of wells which barely enter the gravel beneath the alluvial clays. At Osborne, a village on Mad River, a few miles above Dayton, drift was penetrated to a depth of 207 feet, but its structure was not learned.

At Miamisburg a portion of the valley has rock near the level of the river bed, but a gas-well boring made in that village penetrated 181 feet of drift, mainly gravel. The deep portion of the valley lying below the level of the stream here seems to be a narrow gorge. The valley above stream level is somewhat constricted for 2 to 3 miles below Miamisburg, though it is probably of preglacial excavation.

From the Great Miami westward along the terminal portions of the morainic loops and northward along the western limb of these moraines the drift is much thinner than in the eastern limb, and contains a larger proportion of till. The majority of the wells are mainly through till, penetrating but little assorted material, though the water-bearing bed at bottom is usually gravel or sand. On the road from Dayton to Chambersburg the wells located on the middle moraine penetrate 30 to 40 feet or more of drift, but north of that moraine in the village of Chambersburg they penetrate but 6 to 15 feet. West from Dayton, in the vicinity of the Soldiers' Home, and northwestward from there in the district lying between the middle and inner members of the morainic system, rock is near the surface; but in the moraines to the north and south the drift has a thickness of 30 to 40 feet or more, and in Stillwater Valley near Little York its thickness exceeds 100 feet. Along the lower course of Twin Creek, as previously described, the drift is exposed to a depth of nearly 100 feet, but in its upper course there are many quarries along the stream, and the amount of drift filling is slight. In the outer border of the morainic system 3 miles southwest of Germantown, on an elevated portion of the uplands, a well on the "Anderson farm" is reported to have penetrated bowlder clay nearly 100 feet without reaching rock. This is the greatest thickness of upland drift reported from this portion of western Ohio.

At Pyrmont (on the inner member) wells 50 feet deep do not reach rock. At Wengertown, West Baltimore, and Gordon, villages situated on the border of the inner member, wells 30 feet deep do not reach rock. At Ithaca, on the inner member, rock is struck at about 25 feet. Flowing wells are obtained along a small creek in this village at a depth of about 15 feet. At Arcanum, near the border of the inner member, one gas well has only 22 feet of drift, but five others have 50 to 55 feet. There is in this village 10 to 20 feet of till at the surface, beneath which the drift is largely sand and gravel.

At Eaton the waterworks well in Sevenmile Creek Valley, in the northwest part of the town, penetrates 75 to 80 feet of drift, mainly till, but in the southern part rock is struck in the valley at about 10 feet. There may, however, be a deep gorge traversing the valley southward, which has not yet been touched in wells. At Camden, about 8 miles below Eaton, the drift in this creek valley has a thickness of 181 feet.

At New Madison there are outcrops of rock in the valley of Whitewater River, but the gas well, which is also in the valley, penetrated 75 feet of drift.

The only records of deep wells obtained in the Indiana portion of this moraine are at Lynn and Losantville. In Lynn one gas well has 117 feet, the other 124 feet of drift. In each well there is about 50 feet of till at the surface, beneath which the drift is mainly gravel. In Losantville the drift has a thickness of 240 feet, the greater part of which is blue till. Some gravel beds were passed through within the upper 100 feet.

BOWLDERS.

Frequent references have already been made to the large number of bowlders which characterize the middle member of this morainic system. Reports by earlier observers, Orton, Hussey, Chamberlin, and Phinney, contain descriptions of portions of the belt,[1] and Chamberlin recognized it as an accompaniment of a moraine of the Miami lobe There are few, if any, bowlder belts within the drift-covered portion of the Mississippi Basin which exceed it in strength and extent of development There is scarcely a mile along the whole length of the morainic loop, from the northern end of the eastern limb in central Logan County, Ohio, around to the northern end of the western limb in Henry County, Ind. (a distance of about 120 miles), in which bowlders are not a conspicuous feature. The belt has an average breadth of more than a mile, not including the eastern limb, in which its breadth is much greater, averaging 2 to 3 miles. The bowlders are much more plentiful in some localities than in others. An estimate made from an actual count of the bowlders at several points gives an average of about ten surface bowlders per acre whose size exceeds 1 foot in diameter. Professor Orton noted a field near West Alexandria, in Preble County, where by actual count there are over 1,200 bowlders per acre which exceed 2 feet in diameter. The aggregate number in any portion of the western limb is probably as great as in an equal length of the eastern limb, since the bowlders are dropped in greater numbers per unit of area in the former than in the latter situation.

The size of the bowlders ranges from a cubic foot or less up to 1,000

[1] E. Orton, Geology of Ohio, Vol. III, 1878, pp. 412–414; John Hussey, Geology of Ohio, Vol. III, 1878, pp. 475–476; T. C. Chamberlin, Third Ann. Rept. U. S. Geol. Survey, pp. 334–335; A. J. Phinney, Fifteenth Ann. Rept. Geol. Survey Indiana, 1885–1886, pp. 112–115.

cubic feet or more, but the majority contain only 10 to 20 cubic feet. They are largely granitic rocks and fine-grained greenstones, but quartzites and conglomerates from the Huronian ledges of Canada are also common. Very few limestone or local bowlders of any kind occur. The vast majority of the bowlders are partially rounded or subangular, but scarcely one in one hundred shows glacial planing. They lie on the surface, or are but slightly embedded in the ground. From accounts given by residents it appears that very few are struck in making wells or other excavations except within a foot or so of the surface. The large proportion of crystalline Canadian rocks, the slight amount of glacial planing, and the restriction of the bowlders to the surface, individually as well as unitedly, indicate that the bowlders were englacial, becoming superglacial at the border rather than subglacial; but the underlying drift appears to be largely subglacial, being composed of thoroughly intermixed local and distant material whose rock fragments are much more conspicuously glaciated than are the surface bowlders. If this interpretation be correct, the amount of englacial material was very slight compared with that of the subglacial.[1]

This bowlder belt continues beyond the limits of the Miami lobe at each end, being traceable southwestward along the eastern limb of a moraine of the East White lobe some 12 to 15 miles, when it loses its strength and can with difficulty be traced farther. In the Scioto moraines, as noted elsewhere in this report, bowlders are present from the reentrant angle in Logan County southward for 30 miles or more in greater abundance than throughout the remainder of the loop, but not in such great numbers as in the Miami lobe. If these continuations of the bowlders into the Scioto and East White lobe be included, the length of the bowlder belt will be increased to about 160 miles. There appears to be no reason for separating the bowlders in the other lobes from those in the Miami lobe. Indeed, they seem to have been deposited at the same time and serve a valuable purpose in indicating the correlations of the moraine.

The outer member of this morainic system has comparatively few bowlders on its surface, the only points where noteworthy numbers were

[1] Comp. Chamberlin: Third Ann. Rept. U. S. Geol. Survey, pp. 331–332; Am. Jour. Sci., May, 1884, pp. 378–390; Bull. Geol. Soc. America, Vol. I, pp. 27–28; Jour. Geol., Vol. I, pp. 47–60. Upham: Am. Geologist, Vol. VIII, Dec., 1891, pp. 376–385; Bull. Geol. Soc. America, Vol. III, pp. 134–148. Salisbury: Am. Geologist, Vol. IX, May, 1892, pp. 304–316.

observed being southeast of Dayton, in the vicinity of Beavertown, and south and southwest of Germantown, but in neither of these places do they compare in number with those in the main belt.

On the inner member the distribution of bowlders is somewhat irregular. The eastern limb is liberally strewn with them throughout its entire length, though they are not so numerous as in the bowlder belt of the middle member. The terminal portion of the loop and the western limb are sparingly supplied with bowlders, but have small areas in which the number is as great as in the main belt.

There are parts of the inner border plain on which bowlders are as numerous as anywhere in the main bowlder belt. The most conspicuous of these tracts lies along the Stillwater River, the bowlders occurring abundantly along this stream for several miles below Ludlow Falls and also on the plains east of the stream along a line running from West Milton to Troy. Over an area of several square miles they are so thickly strewn that stone wall fences are made from them and they form a serious hindrance to the cultivation of the soil. The entire district embraced between the morainic system under discussion and the next moraine to the north is plentifully supplied with bowlders, scarcely a farm being free from them, but they seldom so greatly interfere with agriculture as they do about Ludlow Falls. These bowlders probably represent englacial material dropped during the recession of the ice sheet. So far as the writer could discover, they do not form belts that can be correlated into well-defined systems or lines and are not so suitable as moraines for showing the outline of the ice margin.

CHARACTER OF THE OUTWASH.

In this discussion the deposits of the valley of Mad River will first be considered, after which the valleys to the west will be taken in turn.

Mad River finds its source in the reentrant angle between the Scioto and Miami lobes, at an altitude about 1,250 feet above tide. There is not such deep gravel filling here as at points lower down in the valley. The village of Zanesville is located in the valley about 2 miles below the head of the river, and it is reported that the gravel has here a depth of but 12 to 20 feet, the remainder of the drift to a depth of 120 feet being mainly clay. The surface of the valley bottom at Zanesville is nearly plane and has the

appearance of a glacial gravel plain. Tributary plains enter near this village from the Scioto moraine on the east, and the valley soon becomes broader, having in Champaign County a width of 2 to 3 miles. The present stream has cut but a shallow channel in the upper half of its course and in flood seasons still overflows the bed of the glacial stream, though it has here, as throughout its entire course, an average fall of about 9 feet per mile. The moraine comes down to the border of this plain west of West Liberty, and probably glacial waters issued from it at this point into the Mad River Valley.

About 6 miles below West Liberty a gravel plain enters the valley from the northwest. It is nearly a mile in average width, and extends fully 3 miles back into the moraine. At its northwest end this tributary gravel plain grades into and fits about the morainic knolls, showing that it is of the same age as the moraine. The plain is traversed by two streams, Muddy and Crayon creeks, whose beds are only 12 to 15 feet below the level of the plain. One of these streams enters from the north and the other from the southwest side of the gravel plain, and they take parallel courses through it, being distant from each other one-half mile or more. The size of their valleys compared with that of the plain which they enter is an indication of the small amount of work they have accomplished compared with that accomplished by the glacial stream which formed the gravel plain.

A few miles farther south, and nearly opposite Urbana, another tributary glacial gravel plain enters Mad River Valley from the west. This plain is 80 to 160 rods in width, and is traversed by Nettle Creek, the source of the stream being near the head of the gravel plain. It lies in a valley which is continued farther west, and into which the moraine descends at the head of the gravel plain, there forming the divide between Mosquito Creek, a tributary of the Great Miami, and Nettle Creek, a tributary of Mad River. The peculiar features here produced by the ice sheet merit a brief description. The moraine consists of a series of gravelly hummocks, rising only 10 to 20 feet above the level of the head of the gravel plain, which occupy the valley for less than one-half mile, and into which the gravel plain merges as if it had been formed in connection with them. The same knolls stand about 60 feet above the level of Mosquito Lake, a lake which forms the head of Mosquito Creek, the stream leading northwest

from the moraine. The ice sheet apparently occupied the northwestern end of the valley while its waters were filling the portion of the valley outside the ice with gravelly deposits, and withdrew without filling up the portion of the valley which lay beneath it to as high a level as the glacial waters had filled that outside.

Near Springfield the present Mad River enters a narrow rock-bound valley for a few miles, but emerges near Snyder's station into a broad plain several miles in width. The plain extends on the northwest nearly to New Carlisle, where it connects with a gravel outwash or apron of the moraine. Here we find phenomena similar to those just described in the Mosquito-Nettle Creek Valley. From the outer border of the moraine there is a plain descending southward to Mad River, while on the inner border is the valley of Honey Creek leading northwestward to the Great Miami, the highest point between the two rivers being at the junction of the moraine with the gravel plain near New Carlisle.

From the expanded portion of the gravel plain under consideration a valley leads southward to the Little Miami River. It is occupied throughout its entire length by Beaver Creek, the head of the creek being in the Mad River gravel plain and the mouth at the Little Miami. It is much smaller than Mad River Valley, its width near Byron and also near its mouth being but 60 to 80 rods. This valley was probably occupied by a stream at the time of the highest stages of the waters which formed the Mad River plain, but seems on account of its small size not to have carried the main stream for any great length of time. The valley may be older than the Mad River gravel plain, though it was apparently somewhat enlarged at the time that plain was occupied by glacial waters.

About 4 miles west from the point where Beaver Creek Valley leaves the Mad River gravel plain, the river enters the outer member of the morainic system under discussion. It joins the Great Miami at Dayton, and that stream passes southward along the inner border of the outer member and leaves the moraine about 25 miles below the point where Mad River entered it, its course throughout much of that distance being about 3 miles back from the outer border of the moraine. This extension of the ice sheet beyond the valleys of Mad and Miami rivers raises some interesting questions. Did this bridging of the valleys by the ice sheet produce an obstruction or dam sufficiently strong to prevent the waters of Mad River

from following their present course? And if a dam was produced, was it maintained continuously throughout the entire period during which the outer member of the morainic system was forming?

That the ice sheet occupied this portion of the valley for a considerable period is shown by the strength of the portion of the moraine developed along the southeast side of the valley, and that it would, while occupying the moraine, present a serious obstruction to the flow of a stream along the valley can scarcely be doubted, especially since the course of the stream did not conform to the direction of ice movement but was almost at right angles to it. The open valley (Beaver Creek), leading southward from the Mad River plain to the Little Miami, to which attention has already been directed, may have been utilized because of an obstruction to the flow of the water down the valley. The obstruction may have been complete for a brief period, but that it was not complete for the entire period required in the formation of the moraine seems to be shown both by the small size of the outlet through Beaver Creek Valley and by terraces along Mad and Miami rivers. The portion of the Mad-Miami Valley under discussion is occupied by a broad gravel plain similar to that along the upper portion of Mad River and much broader than that along the portion of the Great Miami above the mouth of Mad River. This plain has, so far as the writer could detect, no trace of morainic features on it where the moraine crosses Mad River above Dayton, and no well-defined morainic features at the point where it crosses the Great Miami below Dayton, the only peculiarity of the plain at the latter place being a series of channels and slight undulations doubtfully referred to glacial action. So far as noted, the Mad River plain has no terraces above the point where the moraine crosses that are not present below that point. Indeed, there seems to be but one broad and well-sustained plain higher than the present flood plain either above or below the point where the moraine crosses, and this has a general elevation of 30 to 40 feet above the river. The great size of the gravel plain in the vicinity of Dayton, when contrasted with the narrowness of the Beaver Creek Valley, supports strongly the view that this portion of the valley afforded a passage for the stream throughout much of the time the moraine was forming.

Mad River Valley was occupied by glacial waters only in the periods during which the outer and middle members of the morainic system were

forming, the position of the inner member being such that water from it could not have been discharged down the valley; and of the two periods the earlier one seems to have furnished nearly all the glacial material to the valley, the glacial terraces leading into the valley being more numerous and also more capacious from the outer than from the middle member.

The Great Miami, above the mouth of Mad River, has a much narrower valley than below, or than the valley of Mad River itself, the general width being one-half mile or less. In the vicinity of Troy it is, for a few miles, expanded to a width of a mile or more, and contains a gravel plain standing about 20 feet above the river, on the borders of which there is a terrace or remnant of a higher plain standing 30 to 35 feet above the river. It is thought that this higher plain may have been connected with the ice sheet at the time the inner member of this morainic system was forming, but the connection is not clearly established. The lower plain appears also to be of glacial age, and apparently finds its head in the Union moraine, a few miles above Piqua. A description of it is given in connection with that moraine.

Below the point where the outer member crosses the Great Miami (near Carlisle) that stream flows through a gravel plain, 1 to 3 miles wide, which, throughout much of its length, stands less than 50 feet above the river, but which near the mouth attains a height of 100 feet above the river owing to the more rapid descent of the present stream. Attention was called on a preceding page to the presence of a buried soil beneath this plain, a few miles below Hamilton, at a depth of about 60 feet. It is thought that the valley received an average filling of at least that amount at the time these moraines were forming, as a result of the overburdened condition of the glacial floods. That the stream which deposited this material was vigorous is shown by the coarseness of the deposit, the greater part of the material being clean gravel, with a general freedom from silty or fine material such as would have been deposited under slack-water conditions.

There is a small gravel apron along the outer border of the outer member on the uplands east of the Great Miami, at an altitude about 200 feet above the river, which is crossed by the Springboro and Dayton pike nearly due east of Miamisburg. It is situated in a narrow plane tract lying between the moraine and some limestone ridges to the southeast, and forms

a divide, the waters from the northeast part of the apron flowing northward to enter the Great Miami near Alexandersville, while that from the southwestern part flows southwestward along the outer border of the moraine, entering the Great Miami near Franklin. On Isaac Miller's farm a well on this apron penetrated gravel of medium coarseness to a depth of 17 feet, where water was obtained. It is Mr. Miller's opinion that the gravelly phase of this outwash apron does not extend much beyond his farm, but that the remainder of the plain is underlain by clay or silt, and has a black mucky soil. The gravelly portion of the apron has a red loamy soil.

On the uplands between the Great Miami and Sevenmile Creek there is also a small outwash apron. It covers 2 or 3 square miles in the vicinity of West Elkton. Its altitude is about 200 feet above Sevenmile Creek and still more above the Great Miami Valley. It occupies a part of the divide between these streams, its eastern portion draining southeast to the Great Miami below Middletown, while its western portion drains to Sevenmile Creek near Collinsville. Exposures near the border of the moraine show well-rounded clean gravel of medium coarseness, which has a variable thickness, owing to the irregularities of the substrata, but its own surface is quite smooth.

The valley of Sevenmile Creek contains gravel terraces which are thought to be of the age of the outer member of this morainic system, but the connection was not clearly worked out. The valley of this creek contains till as well as gravel below the point where the moraine crosses, the till being capped by a coating of gravel several feet in thickness. Above the point where the outer member crosses there is far less gravel than below, the outwash from the later members being chiefly sand or silt. This valley has been deepened but little since the gravel terraces were formed, their surfaces throughout much of the lower part of the valley being only 30 or 40 feet above the present stream, while the bluffs bordering the glacial terrace rise to a height of 200 feet or more above it.

On the uplands west of Sevenmile Creek there is, in the vicinity of the State line, an extensive till plain just outside the outer member of this morainic system, whose surface on the border of the moraine is capped by a silt deposit 1 or 2 feet in thickness which appears to be a morainic outwash. The extent of the silt deposit was not determined, though it is

known to be absent from portions of the plain a few miles distant from the border, and quite uniformly present near the border of the moraine. The plain occupies a part of the divide between the Whitewater and Great Miami rivers, and stands much above the level of the gravel terraces in these valleys. The presence of gravel terraces in the valleys is evidence of high altitude and good drainage, and, assuming the silts to be of the same age as the terraces, it is evident that the conditions of slack drainage under which they were deposited is not attributable to a low altitude of the country. It seems instead to be due to the absence of drainage channels adequate to connect the plain with these valleys.

This interpretation naturally raises the question whether the silts which cap the Illinoian drift sheet in the district outside the outer Wisconsin moraine were also formed when the country was sufficiently high to afford good drainage had channels been opened. Were these older silts confined to poorly drained portions of the uplands, they might be very inconclusive evidence of a low altitude of the country, but since they cover, as well, districts which would have had good drainage were the altitude high, and districts where no known obstruction to drainage could have existed, their presence is considered conclusive evidence of low altitude.

Several of the tributaries of Whitewater River, in Wayne County, Ind., carry gravel plains which apparently find their head in this moraine system. The head of the plain on East Fork is found in the middle member near the point where it crosses the State line, the Ohio portion of the valley being occupied by drift hillocks, while the Indiana portion carries a smooth plain underlain by gravel. On Nolands and Greens forks there are broad plains from the outer member southward and somewhat narrower plains extending up to the middle member. It is probable that the main gravel filling occurred while the ice sheet was forming the outer member. On Martindale Fork the gravel plain finds its head at the outer member nearly due east of Hagerstown. The plain along this stream is much broader near its head than a few miles below, its width at the head being a mile or more. This plain is called the "Walnut level," on account of the level surface and the walnut timber which occupies it. On the west fork there is only a narrow plain, that stream having been a less important glacial outlet than Martindale Fork.

With the exception of East Fork, all the tributaries of Whitewater are

flowing in valleys that are usually deeply filled with gravel. There is, however, occasionally considerable till beneath the gravel. East Fork has in places but a small amount of drift, for it is largely in a new course opened since the early Wisconsin stage of glaciation. At Richmond the stream has cut about 50 feet into the rock, while the depth of rock excavation is still greater farther south. The other tributaries of Whitewater have for many miles south from the moraine shallow valleys, their beds being but 15 to 30 feet below the glacial terraces.

It is probable that the Whitewater Valley received important contributions of glacial gravel throughout its entire length at the time this morainic system was forming, for the feeders are numerous and the valley has a rapid descent, there being in the gravel terraces a fall of nearly 500 feet between their heads and the mouth of the stream, a distance of about 75 miles. It is not certain whether the terraces formed at the early Wisconsin stage rise at any point above the level of the gravel filling which accompanied the glacial stage under discussion.

STRIÆ.

Thirteen observations of striæ have been made, or have come to the writer's notice within the limits of this moraine and its inner border plain. With two exceptions these are all in the eastern portion of the district. With three exceptions they bear either directly or obliquely toward the eastern limb, the exceptions being found near Piqua, where the bearing is nearly due south and in western Darke County, where the bearing is slightly west of south. Striæ are rare in the western portion of the morainic loop, several rock outcrops having been examined, both within the western limb and on the inner border plain, without success in finding striation. The following is a list of the observations. The bearings obtained by the writer and probably those by other observers have not been corrected for magnetic variation.

Striæ in the vicinity of the main morainic system.

Angel's quarries in Bellefontaine	S. 10° E.
Stattler's quarries, 1½ miles south of Piqua	N.-S.
Zinn's quarry, 3 miles northeast of New Carlisle, near outer border of moraine	S. 22° E.
At roadside, 1 mile west of Zinn's quarry	S. 80° E.
Troy, 6 miles southeast of, on east-west center road in Elizabeth Township	S. 25° E.
Troy, 2 miles south of, on west bluff of Great Miami	S. 28° E.
Light's quarry, Dayton, 6 miles north of, east bluff of Great Miami[1]	S. 19°-33° E.

[1] Reported by Dr. John Locke, Geology of Ohio, 1838, pp. 230-232, fig. 2.

Dayton, 4 miles southeast of, in Beavertown quarries[1]	S. 27° E.
Liberty, 1 mile northeast of, on west bluff of Great Miami	S. 28° E.
Liberty, 3 miles north of	S. 28° E.
Near West Milton, east bluff of Stillwater River	S. 30° E.
Gard's quarry, near Greenville[2]	S. 5° W.
Weavers station, Darke County[2]	S. 5° W.

INNER BORDER PHENOMENA.

The district lying between this morainic system and the next moraine to the north varies in width from 20 miles in the axis to a narrow neck with a width of 5 miles or less near the borders of the lobe. It has throughout nearly its entire extent a very smooth surface. Along portions of the valleys, however, a few drift knolls of large size occur. The valley of Mosquito Creek, which enters the Great Miami near Sidney, contains several very sharp knolls 50 to 75 feet high; smaller ones are found in the Miami Valley in the vicinity of Piqua and between Piqua and Troy, and there are other belts along tributaries of White River in Indiana. These valley knolls form chains nearly at right angles with the course of the moraine, and since they are comprised largely of gravel it is thought that they may have been formed by subglacial streams in their passage toward the ice margin, and are, perhaps, to be classed as imperfect eskers.

The surface of the upland, as remarked above, is liberally strewn with bowlders, and in places they form a conspicuous feature. The drift consists largely of till, and owing to the irregularities of the underlying rock surface presents much variation in thickness, as shown below.

The gas-well boring at Port Jefferson, in the Great Miami Valley, 5 miles above Sidney, penetrated about 300 feet of drift, but in the same valley, from Sidney southward, rock exposures are numerous up to a level within 50 or 75 feet of the bordering uplands. At Piqua there are quarries in the valley, but a well at Mr. Wiley's, 1½ miles north of the city, extends to a level nearly 150 feet below the river bed without reaching rock, and one at Joseph Sawyer's, on the bluff in the west part of the city, strikes rock at a level fully 100 feet below the river bed. The well driller, J. M. Stoker, of Piqua, reports that Wiley's well was in gravelly material for about 30 feet, beneath which 140 feet of blue till was penetrated. In Sawyer's well 8 or 10 feet of yellow till was succeeded by about 20 feet

[1]The main bearing is S. 26° E. Orton's map, Geology of Ohio, Vol. I, p. 413, indicates striæ in that vicinity bearing S. 18° E.

[2]Geology of Ohio, Vol. III, p. 501.

of gravel, beneath which there was blue till extending to the rock, which was struck at a depth of 190 feet.

On the uplands bordering Stillwater River the drift seldom exceeds 50 feet, and is, in places, 10 feet or less in thickness, while along the river there are rocky bluffs with scarcely a break throughout the entire course of the stream through this plain.

Toward the west the thickness of the drift increases, borings near Union City having 60 to 200 feet or more, while those west and south of Winchester, Ind., show a range from 80 to 333 feet. In wells in the vicinity of Union City the drift contains but little assorted material, and the same is true in the majority of those near Winchester. The boring near Winchester (about 1½ miles west), in which 333 feet of drift was penetrated, passed through a large amount of quicksand. The Lockport (Niagara) limestone, which covers nearly the whole of the elevated portion of eastern Indiana, was absent in this well and also in one north of it, on the north side of White River. In the latter well also there was more than 300 feet of drift.

SECTION II. IN THE SCIOTO LOBE.

THE MEMBERS OF THE SYSTEM.

DISTRIBUTION.

This main morainic system connects definitely with that of the Miami lobe on the uplands of Logan County and also with a similar morainic system of the Grand River lobe. There are perhaps some advantages in setting forth the distribution in the reverse order from that here presented; but, as originally prepared, this part of the Monograph dealing with the Scioto lobe was intended to be published as a separate bulletin of the Survey; and since it would involve a practical rewriting of the paper to reverse the order of presentation, the old order has been retained.

This morainic system, as shown in the glacial maps (Pls. II and XIII), connects on the northeast with the western limb of the outer moraine of the Grand River glacial lobe, forming with it an interlobate belt which occupies much of Stark County and extends northward through eastern Summit and western Portage counties to a later morainic system, which continues the interlobate tract into Geauga County.

From southern Stark County the morainic system under discussion swings abruptly westward, and between there and Mansfield covers a tract 8 to 14 miles wide, the greatest width being in the vicinity of Killbuck Creek, where it is separated into three somewhat distinct belts with intervening tracts 2 miles or more in width, in which morainic features are rare.

Immediately west of Mansfield the whole system swings abruptly southward. Its breadth for a few miles along the western border of the highland tract of Richland County is but 5 or 6 miles, but south of this tract it spreads out, the main belt continuing southward, while a somewhat distinct outer moraine passes eastward along the south border of the highlands nearly to Mohican Creek at Greersville, where it also turns southward. At this eastern point it is separated by an interval of but 4 miles from the outer portion of the moraine that lies north of these highlands.

Where this eastern member of the belt swings southward (near Greersville), the breadth covered by the whole morainic system is fully 25 miles, but the strongly morainic features are found mainly within the western half. There is scarcely a square mile, however, on the eastern half of the belt which does not contain drift knolls of rather sharp contour. Apparently the eastern portion was occupied by the ice sheet for a much briefer period than the western, the drift being thinner as well as less closely aggregated into knolls and ridges.

From this point of greatest expansion the eastern and western members converge, the breadth of the system decreasing toward the south to about 16 miles, in the latitude of Newark, and 13 or 14 miles at the Licking reservoir, and southward from there to Lancaster. The system consists, near Lancaster, of three distinct members, separated from each other by intervals of 2 to 3 miles, in which morainic features are rare. Throughout this north-to-south portion of the eastern limb of the Scioto lobe one member, the inner or western, is maintained distinctly and has a breadth ranging from 4 up to 10 miles. The remainder of the system is made up of two more or less distinct members, whose variations in width and strength are great, as shown in Pl. XIII.

Near Lancaster the morainic system shifts abruptly westward a few miles, producing the appearance of a shoulder or slight lobation north of the city, after which it trends west of south to the Scioto River, the inner

member coming to that stream near Circleville and the outer some 14 miles farther south.

West from the Scioto River for 15 miles or more the morainic system leads over a hilly district and morainic features have an interrupted development, the inner member, which east of the Scioto is everywhere strong, becoming here vaguely defined; but in western Ross County the morainic system again shows distinct members, four of them being readily traced northwestward from this county.

The outer one follows the southwest side of Rattlesnake Creek across northeastern Highland County. Leaving this creek, it continues northwestward through Clinton and northward through eastern Greene County, constituting the divide between tributaries of the Scioto and Little Miami rivers. Continuing north, it enters the Miami drainage area in Clark County, and is distinctly traceable about to the latitude of Springfield, where it becomes difficult to trace because of its close association with later members of the system. This belt is the one whose course is outlined by Professor Chamberlin in the Third Annual Report. Its breadth is about 2 miles, and it is clearly distinguishable, by its prominent morainic features, from the nearly plane tracts on either side.

The second member of the system follows the northeast side of Rattlesnake Creek from its mouth to its source and determines the course of that stream. It becomes merged with later belts in southeastern Clark County. Its width is scarcely a mile, but throughout its entire length it presents sharp knolls and ridges that produce a strong contrast with bordering plane tracts.

The third member passes from Roxabell, in Ross County, in a course north of west, lying mainly south of the Dayton and Southeastern Railway, to Paint Creek, which it crosses between Washington and the mouth of Sugar Creek. From Washington its course is northward along the east side of Sugar Creek to the source of that stream, and thence a few miles north in conjunction with the member west of it. It then becomes merged (near the latitude of Springfield and London) with the remaining members of the system. This member has a general width of about 2 miles.

The fourth member follows the southwest side of North Paint Creek for a few miles in northwestern Ross and southeastern Fayette counties. It leaves that stream near the line of the Cincinnati and Muskingum Valley

Railway, and passes northwestward to Bloomingburg. From that village it passes northward along the east side of a tributary of Paint Creek to its source near Midway, and continuing north passes the Madison County infirmary, 3 or 4 miles west of London, near which it becomes merged with earlier members. Its breadth is a mile or more. Reference is made to this belt by Chamberlin in his paper in the Third Annual Report.

The combined moraines pass northward through northeastern Clark, eastern Champaign, and southeastern Logan counties, constituting a belt 6 to 9 miles wide, the width decreasing northward. Near Bellefontaine it connects with the main morainic system of the Miami lobe, as already indicated (pp. 354, 382).

RANGE IN ALTITUDE.

From the northern end of the interlobate tract on its eastern margin, westward to the meridian of Wooster and Millersburg, the moraine has few points that exceed 1,300 feet above tide, and none that fall below 800 feet. A change of altitude of 250 feet is frequently made, however, within a distance of 1½ to 2 miles in passing from ridges to valleys. In Killbuck Valley, between Wooster and Millersburg, the moraine is lower than at any other part of this shoulder of the lobe, being but little more than 800 feet above tide. The hills near this creek are capped by drift ridges of morainic type at an altitude of fully 1,100 feet. Near Mansfield, on high points 2 or 3 miles southwest of the city, drift knolls occur at an altitude of 1,490 feet (barometric). The principal valleys in that vicinity are 1,100 to 1,150 feet, making the range in altitude within short distances about 350 feet.

In the eastern limb of the main lobe the strongest part of the moraine occupies the divide between the Scioto and the Muskingum and Hocking drainage systems, but owing to the hilly character of the region the range in altitude is not slight. There are parts of the Hocking and Licking valleys where the altitude is but little more than 800 feet above tide, while on neighboring hills it is 1,100 to 1,200 feet or more. In many places changes of altitude of 250 to 300 feet occur within a mile or two.

In the Scioto Valley and the lower portion of Paint Creek Valley morainic features are developed at an altitude as low as 700 feet above tide, while on neighboring hills north of Paint Creek they occur at an altitude of 1,150 feet.

In the western limb the outer member follows so nearly the water

parting between the Miami and Scioto drainage basins that it has no large valleys to cross, and as the district is not so hilly as on the east border of the lobe no abrupt changes in altitude occur. There is, however, a gradual increase in altitude in passing from south to north, the altitude in western Ross and northwestern Highland counties being about 1,100 feet and in eastern Logan County 1,400 to 1,500 feet. The other members of the morainic system show about the same range in altitude as the outer one, the altitude of the eastern member being about 900 feet at the line of Ross and Fayette counties and 1,300 feet or more in Logan County. This member of the moraine may perhaps include the highest points in Logan County and reach an altitude of 1,500 feet above tide, for it is possible that the ice sheet extended to these high points down to the time this member was forming.

RELIEF.

In each of the several members of the western limb the outer border is abrupt and quite marked, though usually but 20 to 30 feet in height; but on their inner border the moraines blend into the plains so gradually that there is no marked relief. The portion of this western limb in which the moraines are not distinct ridges (in Logan and Champaign counties) stands in places 200 feet above the valley of Mad River, which in Logan County follows its outer border, but this relief is due in part to an underlying rock ridge, the thickness of the drift of the moraine being less than 200 feet. There is in this portion of the moraine an inner border relief nearly as great as is the outer, which is also due in large part to its location on the rock ridge.

The eastern limb of the main lobe is not so distinctly ridged as the western. The member that follows the water parting has a higher altitude than the remainder of the system, but this is due to a rock ridge rather than to increase in thickness of drift, though the drift in this member is considerably thicker than in the members or portions of the morainic system east of it, and the rock ridge is interrupted by notable gaps which have been completely filled with drift.

In the shoulder east of Mansfield the thickness of the drift in the moraine is, on the whole, markedly greater than on the tract northeast of it, but so much variation exists that the amount can hardly be estimated. The interlobate tract, though as a rule more heavily covered with drift than the

district west of it, does not possess a marked relief. This is due to its being heaped up in irregular accumulations instead of in the form of a definite ridge.

TOPOGRAPHY.

The height, degree of sharpness, closeness of aggregation, form, and trend of the knolls and ridges which constitute this morainic system, vary greatly, both in the pronouncedly morainic and in the more vaguely defined portions of the belt. In general, however, it may be said that the system consists of rather small but well-defined knolls and ridges somewhat closely aggregated. The height of knolls and ridges usually falls below 20 feet, though instances were noted where it becomes as great as 75 feet. A knoll 20 feet in height covers usually 2 acres or more, though it occasionally occupies a much smaller area. The prevailing form is a somewhat symmetrical cone, but in association with knolls of this form there are hillocks with irregular or hummocky surface, and ridges with various form and trend. Basins are not common except in the interlobate portions, and even there they are not conspicuous. In the interlobate belt formed at the junction of the Scioto and Grand River lobes, there are several basins a square mile, more or less, in area, which are occupied by small lakes. The most prominent of these are the Twin Lakes, near Earlville, in Portage County, and Springfield, Summit, Long, Turkeyfoot, and Mud lakes in Summit County. Of these, all except Springfield Lake lie in gravel plains whose general level is but a few feet higher than the surface of the water, but Springfield Lake is bordered on all sides by prominent moraine hillocks.

The portion of the interlobate tract lying north of the bend of the Cuyahoga was formed, in part at least, in conjunction with a later series of moraines in connection with which it will be discussed.

South of the bend of the Cuyahoga, the interlobate moraine lies mainly east of the meridian of Akron, and is so closely associated with the western limb of the main Grand River morainic system that no distinct line of separation could be found. A line drawn directly from the point of separation near Canton, northward past Kent, passes through a goodly number of small gravel plains situated among the moraine hillocks, and these features appear to be the natural results of a junction of ice lobes, while the striæ on either side of this line indicate clearly a movement from

opposite directions toward it, those on the west being eastward and southeastward, while those on the east are westward and southwestward. But in the course of the formation of the interlobate tract, the line of junction between the lobes (or their individual margins in case no junction was effected) may have shifted back and forth to a distance of several miles. On the assumption that this is the line of junction, there remains a belt 5 or 6 miles wide west of this line, which is sharply morainic. The knolls seldom exceed 60 feet and are usually scarcely 30 feet in height, but they have, as a rule, very sharp contours.

West of this strong belt there is a gravel plain one-half mile or more in width, which runs from the bend of the Cuyahoga southward through Akron to Turkeyfoot Lake. On its western border there is a feeble morainic belt in which basins are a prominent feature. Some basins 20 feet or more in depth have an area of scarcely one-half acre each. This moraine is well exhibited from the west part of Akron northward along the west bluff of Little Cuyahoga River and also west of New Portage. Its width is a mile or less. West of this is another gravel plain called Ayer Flats, which is 1 to 1½ miles wide and runs southward several miles from near the forks of the Cuyahoga to the Tuscarawas, its southern end being known as Copley Marsh. This gravel plain was apparently a line of outwash from the outer member of a later series of moraines which crosses the Cuyahoga near the bend below the mouth of the Little Cuyahoga.

From a few miles north of Canton a narrow outer belt continues nearly south to the Tuscarawas Valley just above Bolivar, while the main belt turns southwestward, crossing the Tuscarawas above Massillon. The outer belt has some prominent knolls near Canton 50 to 75 feet in height, but as a rule its knolls fall below 20 feet. They are seldom so closely aggregated as in the united belt farther north. This outer belt apparently forms the glacial boundary and shows an interesting irregularity of outline on its outer border, there being in nearly every valley or lowland tract a projection of the moraine beyond the line on the bordering hills, the amount of projection being in some cases a mile or more. This is well shown on the road from Canton to Bolivar, where scarcely a trace of drift appears on the uplands, while in the valleys drift abounds in sharply outlined knolls and ridges which rise abruptly 10 to 15 feet. A similar irregularity of border was noted farther west along the road leading from Wiensburg through Berlin to

Millersburg. The freshness of contour of this outer member is such as to denote that it is not much older than the other members of the morainic system.

The main member, which crosses the Tuscarawas Valley above Massillon, consists of closely aggregated, sharp knolls, 20 to 50 feet high, among which are occasional basins. The morainic topography west of the Tuscarawas is much weaker in expression than it is east of that stream, the knolls from the Tuscarawas westward to Killbuck Creek being usually but 10 to 15 feet high, and less closely aggregated and gentler in slope than in the interlobate tract. On Pl. XIII, two, and, in places, three, members of the morainic system are indicated as crossing from the Tuscarawas to Killbuck Valley; but it should not be understood that the belts have a clearly defined line of separation; there is simply a comparative scarcity of drift knolls in the portions indicated as nonmorainic.

On Sugar Creek Valley there is, toward the south from the glacial boundary at Beach City, a well-defined gravel plain or terrace, standing about 35 feet above the stream, while toward the north the valley is occupied by morainic knolls of gravelly constitution, and terracing is not well exhibited. The terrace here appears, therefore, to connect with the outer member of the morainic system. The knolls at the head of the terrace are small, 5 to 10 feet in height, but farther north rise in some cases to a height of 20 to 25 feet.

In Killbuck Creek Valley there is at the glacial boundary a morainic accumulation, filling it up to a height of 75 to 100 feet or more, whose surface is gently undulatory, having knolls only 10 to 30 feet in height. South from the glacial boundary is a plane-surfaced terrace standing about 70 feet above the creek. Wright called attention to this terrace in his paper on the glacial boundary in Ohio, in the following words:

> The terraces upon the Killbuck are extensive both above and below the glacial limit. One mile and a half below Millersburg, on the west side, on the farm of A. Uhl, is a terrace about a quarter of a mile wide, containing kame-like ridges and knolls, the surface of which is 102 feet above the flood plain. This gradually rises until it is merged in the till of the hills beyond. Two miles farther south, in the northwest corner of Mechanic township, near Stuart Mills, the terrace is composed of finer material and is level-topped, and gradually descends toward the south, being here but 70 feet above the flood plain.[1]

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[1] G. F. Wright: The Glacial Boundary in Ohio, Indiana, and Kentucky, 1884, pp. 45, 46.

It will be observed that the gravelly knolls in the valley, as well as the level-topped gravel deposits, are included by Professor Wright in the terrace. In the writer's description the terrace is considered to have its head where the level-topped gravel deposit begins. The gravelly knolls are included in the moraine, since they owe their existence largely to the mechanical agency of the ice sheet, like portions of the moraine on the uplands. With this in mind the reader will find no difficulty in harmonizing the two descriptions.

The moraine fills the valley for a couple of miles north from the glacial boundary. There is then an interval of 3 miles or so where the valley is comparatively open, and is bordered by a low plain nearly one-half mile in width. Near Holmesville this low plain rises into a gravel terrace, and about three-quarters of a mile north of that village the terrace heads in the middle member of the morainic system. At its head it stands 35 or 40 feet above the creek. It is well displayed on the east side of the valley. In the western portion of the valley there is a low plain which has no connection with the middle member, but passes entirely through it and also through the inner member, the middle and inner members extending down to the borders of the plain on either side of the valley. The width of the plain is nowhere less than one-fourth mile, and in the vicinity of Wooster it expands to a mile or more. It was occupied by glacial waters at a later date than the time when this morainic system was being formed, probably while the ice margin stood near the continental divide. The inner member crosses the valley 2 to 4 miles below Wooster, but no terrace was discovered in connection with it. The morainic knolls in this valley seldom exceed 30 feet in height, and more commonly are but 10 to 15 feet.

Between Killbuck Creek and Lake Fork of Mohican Creek there are, near the southern border of the drift, large dome-shaped hills, 50 to 100 feet in height, covering 20 to 40 acres or more each, which probably contain in every case a nucleus of sandstone, but whose outline is markedly in contrast with that of unglaciated hills near them on the south. In one large hill, about a mile south of Nashville, the north slope was smoothed, like its neighbors, by the ice sheet, while the south side remains rough, like hills in the unglaciated district, and is covered by immense detached masses of sandstone. The drift knolls in this district are but 10 to 20 feet high. They present fresh contours out to the very borders of the glaciated district.

No indication of an attenuated sheet of drift was noted south of this outer member. In the middle member of the morainic system, near the line of the Pittsburg, Fort Wayne and Chicago Railway and between the villages of Lakeville and Shreve, the morainic knolls are somewhat larger, but none exceeding 40 feet in height were observed. A few basins occur among the knolls. The northern member is well exhibited a few miles north of this railway, in the vicinity of Springville, and thence westward to Lake Fork. The several members become combined near Lake Fork, and it is probable that for a few miles west from that stream the middle member has overriden the outer, for the knolls south, southeast, and west from Loudonville have a size and sharpness somewhat greater than the outer member usually displays, their height being often 30 feet or more, and that, too, at altitudes fully 1,100 feet above tide. Some basins occur among the knolls where closely aggregated. These features are more common on the middle than on the outer member.

In the valley of Lake Fork there is a terrace standing at the glacial boundary about 100 feet above the creek. At Greersville, 4 miles south of the glacial boundary, it has a height of only 75 feet, and at Gann, 4 miles farther south, its height is not more than 60 feet. Upon following up Lake Fork from the glacial boundary one soon finds knolls at an altitude lower than the terrace. For several miles the high terrace appears at intervals along the border of the valley, while in the midst of the valley, at considerably lower levels, there is a knob-and-basin topography. The basins cover several acres and the centers are depressed 10 to 15 feet or more below their rims. Their bottoms are peaty and marshy, and therefore presumably filled to some depth. They are surrounded by knolls of various sizes, form, and trend, while near them at the border of the valley are level-topped gravel deposits standing 50 feet or more above the general level of the morainic tracts in the valley. Phenomena somewhat similar to these are displayed in several valleys in northwestern Pennsylvania just above the glacial boundary, and may be common in other parts of the glaciated district. Their cause is not well understood, but it is thought that they are probably due to the lingering of an ice mass in the central portion of the valley after a passage for the escape of water from beneath the ice had been opened along the borders of the valleys. The ice sheet may have been broken up and the terraces formed around its detached masses,

or it may have been comparatively unbroken, but traversed by tunnels in which the terraces were built up. About 5 miles north of the glacial boundary a remnant of the high terrace was noted, which was bordered by a low sag on the side next the bluff, resembling somewhat the sag which so often accompanies the esker ridges. Phenomena such as these may serve as a connecting link between the eskers, which are probably subglacial, and moraine-headed terraces which, having their origin at the ice margin, are extraglacial. The morainic features and the high, level-topped terraces both disappear somewhat abruptly near the north border of the moraine, and the valley for some miles above has a low, nearly smooth, plain but little higher than the stream. From this it appears that the ice sheet at the late Wisconsin invasion deposited but little material in this valley except at its margin, a feature not uncommon in other valleys of northeastern Ohio and northwestern Pennsylvania.

On the uplands bordering Lake Fork the sharpest knolls and ridges are found near the southern border, there being in the northern portion gentle till swells but 10 to 20 feet high.

The moraine is exceptionally strong from Lake Fork westward past Loudonville and Perrysville to the vicinity of Lucas. In a lowland tract south and west of Perrysville numerous knolls and ridges rise abruptly to a height of 30 to 50 feet, and among them landlocked basins occur. It is probable, as indicated in Chapter III, that Clear Fork and Black Fork had, in preglacial times, a course north of the present one, from the lowland tract near Perrysville eastward, near the line of the Pittsburg, Fort Wayne and Chicago Railroad, past Loudonville to Lake Fork, as a lowland tract there occurs a mile or more in width, deeply filled with drift, while the present streams are in narrow, rock-bound valleys for several miles above their junction with Lake Fork. This lowland tract is now occupied by a strong morainic belt.

East from the reentrant angle near Mansfield the moraine for several miles is weak compared with its strength on the west side of the reentrant angle, or compared with its strength a few miles farther east. It is represented by scattering drift knolls and occasional low ridges whose height seldom exceeds 20 feet. The striæ east of this reentrant angle, near Windsor and Mifflin, instead of bearing west of south toward the moraine, bear southeastward, approaching it at an oblique angle, a fact which strengthens

the view that this portion of the district is a shoulder rather than a distinct lobe. By this interpretation the moraine here in its weakly developed portion is lateral rather than terminal. Farther east the striæ bear southward or at right angles to the moraine, so that the moraine is there terminal in its position, and its strength is greater than where lateral. West of the reentrant angle, near Lexington and Iberia, striæ bear obliquely toward the moraine, but it is nevertheless strong, the movement in the main lobe being more vigorous than that on the shoulder. The variations in the strength and direction of ice movement seem therefore to afford ample cause for such variations in the strength of the moraine as are displayed.

In the midst of the elevated district lying southeast of Mansfield there is a small tract known as Chestnut Ridge, on which careful search along several routes failed to disclose any drift. It takes the form of a narrow neck about 3 miles in width and 10 or 12 miles in length, which extends from Mohican Creek, just above Greersville, westward nearly to Independence. Its altitude is scarcely 100 feet greater than that of districts bordering it on the north and south, being about 1,400 feet above tide, and it is somewhat lower than drift-covered hills lying northwest of it, which in some cases reach an altitude about 1,500 feet above tide. These hills to the northwest, however, are not heavily glaciated, the drift being but a few feet in thickness, and showing little tendency to aggregation in knolls. Around this tract of thin drift curves the moraine under discussion, the trend being from south of east to north of west on its north side, north to south on its west side, and north of west to south of east along its south side. On the meridian of Mansfield the distance from the portion of the moraine on the north to that on the south of this tract of thin drift is 10 or 12 miles; but on the meridian of Perrysville, 10 miles east of Mansfield, the distance is but 5 or 6 miles, and at the Mohican Creek it is scarcely 4 miles. The space is so narrow in this eastern portion that Wright and Wooster each connected morainic features on the south with those on the north. Thus, Wright carried the glacial boundary from near Greersville northward to the mouth of Lake Fork along the west side of Mohican Creek,[1] and Wooster carried the moraine from Fredericktown direct to Perrysville.[2] Taking into consideration the bearing of the striæ, the position of the thin

[1] See Glacial Boundary in Ohio, by G. F. Wright, 1884.

[2] See map (Pl. XXXI) accompanying Chamberlin's paper in Third Annual Report, U. S. Geol. Survey, 1883.

drift tract, and then the course of the morainic belts bordering them on the north, west, and south, there seems reason for concluding that the ice currents parted a few miles northwest of this elevated district, one portion of the ice passing southeastward along the northern side of the highlands, while the other passed nearly south along the western side, and then swung eastward, doubling about the southern side. A cause for this parting of currents and winding of the ice sheet is found in the obstruction presented by this highland tract, whose highest points stood 200 feet or more above the general elevation of the districts north and south of it, the highlands being 1,400 to 1,500 feet above tide, while the bordering tracts are 1,200 to 1,300 feet. The ice sheet seems to have overridden the highest hills, but not to have had sufficient force to continue beyond them, while the stronger currents on the lower lands, both to the north and the south, continued eastward, and by their convergence nearly coalesced east of these highlands. Though partially overridden by the ice sheet, the highlands seem not to have been subjected to so long nor so vigorous glaciation as the lower tracts that surround them.

Northwest and west from Mansfield the moraine consists of closely aggregated knolls 15 to 20 feet, more or less, in height. Near Lexington the knolls occasionally reach a height of 30 feet or more. Basins are numerous in the vicinity of that village on the lowland tracts bordering Clear Fork. Several were observed which have an area of about an acre and a depth of 15 or 20 feet. They occupy a gravel plain which stands 40 or 50 feet above the stream. This gravel plain constitutes the head of a terrace, and is of importance, since it apparently indicates that the ice margin, at the time the main moraine was forming, was as far west as Lexington. Instead of crossing Clear Fork 20 miles southeast of Mansfield, as interpreted by the earlier students, it seems more probable that it crossed the stream 6 miles southwest of that city.

The knolls near Fredericktown, just referred to, are in chains which have a northwest-southeast trend, following nearly the course of the West Fork of Owl Creek. They constitute the border of the moraine that sweeps around the western end of the belt of thin drift whose outline was given above, and they lie several miles east of the main morainic belt. Their contours are sharp, and the larger ones rise abruptly to a height of 25 or 30 feet. This member of the morainic series appears to continue directly east

from Fredericktown, there being just south from North Liberty and Jelloway a series of drift knolls and drift ridges 10 to 20 feet high. Eastward from North Liberty the drift knolls set in at the very border of the high ridge that seems to be driftless, but westward from this village there is an outlying belt of thin drift. As noted above, the morainic features within the tract lying between the main moraine and the glacial boundary south of the abrupt turn in the boundary are not so clearly outlined as in the main moraine, yet scarcely a square mile occurs which does not contain drift knolls of rather sharp contour. The whole may perhaps be considered a morainic tract formed during the brief space in which there was lobation on the south border of the nearly driftless highland. In presenting morainic features it differs from the tract with thin drift which lies on the border of the highland, there being in the latter little or no aggregation in knolls or ridges.

Between Mount Vernon and Newark the moraine presents marked differences in topography. For 5 or 6 miles, perhaps more, on its western border it has closely aggregated knolls and ridges constituting a continuous, well-defined moraine. East of this main belt the knolls and ridges of drift are very unequally distributed, there being areas of a square mile or more where drift knolls are as closely aggregated as in the main belt; but equally extensive tracts appear which have very few knolls. No decided differences in age were detected between the main moraine and the knolls of the district east of it; on the contrary, the one seems to be a close successor of the other. The eastern part of the moraine shows strong development from Mount Vernon southward as far as Utica along the east side of the Baltimore and Ohio Railway; also about the Licking reservoir south of Newark, and south from there to Pleasantville. The knolls in these situations, though no higher than in bordering tracts, are more closely aggregated and consequently give stronger expression to the belt. They are ordinarily but 10 to 25 feet in height, are usually conical in form, and have gentle slopes.

In the vicinity of the Licking Valley, both to the northeast and southwest of Newark, the drift is aggregated in knolls even where it fails to form a continuous sheet, many of the elevated hills and ridges showing scarcely a trace of drift, while the lowland tracts among them are dotted with drift knolls. In the district northeast of Newark these features are displayed to

advantage along the direct road from Newark to Wilkins Run, and thence to St. Louisville, and in the district southeast along the road from Newark to Linnville, and thence west along the National road to the valley of South Fork. There is a lowland tract, lying northeast of Newark, with a general elevation about 100 feet above the Licking River, which Wright refers to in his paper on the glacial boundary (p. 53) as a terrace. It is, however, dotted by drift knolls 10 to 20 feet in height, among which shallow basins are inclosed, the whole aspect being morainic. In structure also it resembles a moraine rather than a river terrace, since it contains much till and its assorted material is frequently disposed in arching or inclined attitudes. On the north side of the Licking Valley, just east of Newark, is a less elevated lowland than that just described, standing about 40 feet above the river. It has slight surface inequalities, but they are perhaps attributable to fluvial action, and being made up almost entirely of gravel, the name terrace is probably applicable. There are also in this portion of the valley two smooth-surfaced gravel terraces, standing about 30 feet and 20 feet above the river, the lower one constituting the plain upon which the business portion of Newark is built. On each of the several forks of the Licking, which unite at Newark, terraces occur at heights of 40 feet or less above the streams. On the South Fork the head of the upper terrace is about 3 miles southwest of Newark, where the valley is crossed in a north-northwest to south-southeast course by a moraine. On the Middle and North forks the terraces are well displayed for a few miles above Newark, but were not traced to their heads. A low gravel plain several miles in extent lies in the angle between the three forks of Licking River west of Newark, and carries occasional low drift knolls. These knolls were apparently formed at the time the gravel plain was being built up, and are thought to indicate that the head of the gravel plain was built up as a submarginal deposit to about its present height before the ice sheet had withdrawn from over it.

The morainic system is, on the whole, stronger northward than it is southward from Newark. Not only are the belts broader, but the knolls and ridges are sharper. South from the latitude of Newark the western or main member is only 3 to 5 miles in width, and with the exception of an occasional large gravelly knoll, the height of its swells and ridges falls below 25 feet. They are, however, closely aggregated, rendering the belt readily distinguishable from bordering plains. The eastern portion of the morainic

system is feebler and the aggregation less close than in the western, the majority of knolls are but 8 to 10 feet in height. In portions of Ross County, however, the outer belt is strong, especially between Adelphi and Hopetown, where the moraine swings westward to the Scioto Valley. The larger knolls there are commonly 20 to 40 feet high, and associated with them are numerous lower ones. Some near Hopetown, noted by Wright, are about 100 feet in height. They are, in fact, short gravelly ridges, with a trend nearly at right angles with the course of the moraine, and may be allied to eskers. Several large gravelly ridges occur on the west side of the Scioto between Paint Creek and North Paint Creek about midway between Chillicothe and Frankfort. These ridges interlock and inclose deep basins. Their height is in some instances 150 to 175 feet above lowland tracts east of them, but scarcely half that above their western bases, which are on a hillside slope.

The terraces and gravel plains along the Scioto River from Circleville southward seem to pertain chiefly to the inner member of this morainic system. A gravelly tract several miles in width, known as the Pickaway Plains, leads down the river from Circleville. It is dotted here and there by drift knolls and ridges of considerable size, and in many places its surface is gently undulatory, but fully one-half the district presents a plane surface. Its variations in topography are probably due to the combined effect of an overhanging ice sheet and a discharge of water from the melting ice. The plane portions of this gravelly area vary somewhat in their height above the Scioto, being about 40 feet in the vicinity of Circleville, while 8 or 10 miles below they are fully 50 feet. This difference is not due to an increase in the altitude of the gravel plain, but to a greater rate of fall of the river, there being a fall of about 50 feet in the stream between Circleville and Chillicothe, a distance of but 18 miles in direct line. The occasional drift knolls on the gravel plain apparently indicate that the ice margin overhung the Scioto Valley for at least 10 miles below Circleville at the time the later moraine was forming. The terraces along the Scioto are discussed on a subsequent page.

The morainic features among the hills of western Ross County are variable. Some of the larger knolls have already been referred to. There are others in the valley of Paint Creek whose height reaches 100 feet or more, and others in a group near Lattas are equally high. Aside from these

large knolls, the height commonly falls below 25 feet. Drift knolls 10 to 15 feet high occur on the elevated tract east of Lattas, in the vicinity of the Greenfield and Chillicothe pike, but such features are not common on the high ridges, the sharply defined morainic knolls in this vicinity being confined mainly to lowlands and valleys.

Of the four members that appear in the southwest portion of this morainic system, the outermost one is by far the strongest. Along Paint Creek, near the mouths of Rocky Fork and Rattlesnake Creek, and thence up the west side of Rattlesnake Creek for several miles, this member is characterized by numerous large, gravelly knolls, many of which are 30 to 40 feet, and a few 75 to 100 feet in height, while among them are many smaller ones. The aggregation is close and the contours are sharp, so that an exceptionally rugged topography is presented. From northern Highland County northward large knolls are infrequent, but closely aggregated knolls and ridges 10 to 25 feet or more in height occur. Besides having these minor ridges and knolls, the moraine carries a basement ridge with well-defined relief of 20 to 30 feet, so that one standing at the base of the knolls is somewhat above the outer border plain. The outer members of this series display generally a ridge with well-defined crest on which the small knolls and ridges are deposited. The height of these knolls seldom exceeds 25 feet and is commonly only 10 to 15 feet, but they are so closely aggregated as to make the belt conspicuous. The intervening tracts between the several members are plane or very gently undulating, with scarcely a knoll worthy of notice.

At their northern ends these several members do not at once form a bold moraine, but for a space of 10 miles or so the features are rather more subdued than in the separate members. But in northeastern Clark County the moraine assumes greater prominence, and from there northward through Champaign and Logan counties it exhibits as strong and characteristic morainic features as anywhere in its course. There are winding and interlocking ridges ranging in height from 10 feet up to 75 feet or even more, among which numerous basins are inclosed. The slopes of the larger knolls are frequently dotted with small knolls and ridges, and carry an occasional basin. Near Mechanicsburg the moraine rises abruptly on its eastern border to the unusual height of 75 or 100 feet, and a series of ridges whose height is 30 to 50 feet and whose contours are exceedingly sharp, lead

northeast from this village for a distance of about 3 miles. The ridges are somewhat disjointed, but at least two well-defined chains exist. These ridges terminate abruptly, but at the northern end of the eastern one is a network of lower ridges, inclosing a small lake. From here the inner (eastern) border of the moraine is shifted 2 miles or more westward, there being a very flat tract toward the north. The moraine west of the plane tract just noted consists of a massive ridge with north-south trend, which has on its crest and slopes a series of knolls and ridges of varying shape, size, and degree of sharpness. The highest rise 30 to 40 feet above their immediate borders, but the ridge on which they are situated has also some variation in altitude, so that in following the crest oscillations of 150 feet or more are in places made within a distance of 2 miles. From the passes, or lower portions of the ridge, gravel plains lead westward into Mad River and Buck Creek valleys, joining the main stream that drained the Scioto and Miami lobes. The most prominent of these tributary gravel streams noted are the following, beginning at the south: (1) On a tributary of Buck Creek, through which the Big Four Railway passes from Mechanicsburg to Catawba station; (2) on a tributary of Buck Creek west and north of Mutual; (3) on a tributary of Mad River from Cables westward; (4) on a tributary of Mad River from Mingo westward; (5) on Mackocheek Creek; (6) Mormon Bottoms, east of Zanesfield; (7) Hadley Bottoms, northeast of Zanesfield.

In each of these tributary plains there appears to have been an outwash of gravel from the ice sheet, and an escape of waters to the Mad River plain. From the crest of the moraine, which forms the water parting in these passes, there was vigorous drainage westward, producing a flat-bottomed valley, while eastward the streams flow among morainic swells until they reach the till plain east of the moraine. This district affords excellent opportunities for studying the phenomena of glacial drainage as well as of glacial deposition.

STRUCTURE AND THICKNESS OF THE DRIFT.

A comparison of numerous slight exposures, such as the region affords, makes evident the fact that the sharply morainic tracts have a larger proportion of assorted material than have those with subdued expression. The knolls which are composed entirely of till have usually gentle slopes. Those which contain gravel and sand with the till may have gentle slopes

but are more likely to be sharp in contour. The large sharp knolls, 75 to 100 feet in height, are almost wholly, while those from 75 down to 30 feet are mainly, composed of gravel and sand. This relation between the form and structure is not an exceptional one confined to this particular morainic system, but a common one in nearly all the moraines yet examined between Wisconsin and New York.

The list of well sections given below serves to bring out a second fact, namely, that the thick deposits of drift in the valleys contain a larger proportion of sand and gravel than deposits of similar thickness on the uplands. This is generally true not only of the morainic tracts, but also of plains between the moraines. It is not uncommon to find a surface deposit of till on uplands and valleys alike, while the substrata in the valleys are assorted material, and those on the uplands are till. This relation between the structure of drift in valleys and that on uplands seems to have wide prevalence in hilly portions of the glaciated districts. Among several causes which may have been operative in producing the phenomena are the following: First, streams flowing from the ice sheet as it made its earliest invasion would, under favorable conditions, deposit much assorted material in the valleys in advance of the ice sheet; second, during oscillatory retreats the ice sheet would be withdrawn somewhat from the valleys, and the assorted material would then, under favorable conditions, be added to the portions outside the ice sheet; third, while the ice was occupying the hilly districts it may have molded itself so imperfectly to the irregularities of the surface as to have left comparatively free passage for waters beneath it along the principal valleys. In the cases cited, where valleys would probably receive contributions of assorted material, the uplands would not be likely to have received such contributions, and it is scarcely probable that an ice sheet under conditions of free drainage, such as the Scioto lobe seems to have had when this morainic system was forming, could do otherwise than fill the valleys with assorted material before the deposition of till had fairly begun. When the valleys became so filled as to greatly impede the flow of water the subglacial drainage would be checked and till would be deposited in the valleys as well as on the uplands. To what extent the valleys were filled at the earlier invasions (Iowan, Illinoian, Kansan and pre-Kansan) is not clearly determined, though the amount was probably great.

In the detailed account of well sections and other exposures of the drift given below, the districts are taken in the following order: (1) The inter-

lobate tract east of the shoulder; (2) the portion of the moraine on the shoulder; (3) the eastern limb of the main lobe; (4) the western limb of the main lobe.

INTERLOBATE TRACT EAST OF THE SHOULDER.

As the portion of this interlobate tract that lies north of the bend of the Cuyahoga was being occupied by the ice sheet at the time when a later series of moraines was forming, the discussion of its structure is deferred, only the portion of the moraine that lies between the bend of the Cuyahoga, near Akron, and the glacial boundary at Canton being taken up here.

In the interlobate tract between the bend of the Cuyahoga and Canton sections showing clayey till are rare, the drift being of a very stony character, not only in the knolls and ridges but in the lower tracts among them. The stony drift is in places poorly assorted, and apparently represents a slightly modified till from which the clayey ingredient is largely removed.

In the Cuyahoga and Little Cuyahoga valleys there are extensive exposures of an exceedingly fine silt or sand forming the main body of the bluffs. It shows distinct lines of bedding, which are usually horizontal but which arch slightly in places or exhibit signs of disturbance. A few pebbles and very rarely a large stone may be found embedded in the sand. The silt is slightly calcareous, and contains in places nodules of carbonate of lime and crystals of sulphate of lime. It is decidedly ferruginous, there being in its upper or oxidized portion numerous balls of iron oxide and thin horizontal bands of iron following lines of bedding. The upper 10 to 15 feet, and occasionally as great a depth as 40 or 50 feet, is of a yellow color, the tints of which are somewhat variable, depending upon the staining by iron. At greater depth it is of a nearly uniform blue color, like the ordinary blue till. Exposures of it 100 feet or more in height occur in the northwest part of Akron, along the Valley Railway, and at numerous points between Akron and Cleveland. Borings show a similar silt below gravel at Summit Lake and Clinton, and at a deep well near Portage. The gravel is connected on the north genetically as well as geographically with moraines that cross the Cuyahoga below "the bend," and lead southward across the present continental divide to the Tuscarawas Valley. The silt is apparently confined mainly to valleys and deeply filled lowland tracts, and was probably deposited in a glacial lake. On uplands and where the drift

is thin there is usually till, gravel, or sand resting directly upon the rock. A fuller discussion of the silts of northern Ohio is given in connection with descriptions of later moraines.

About 1890 a deep well was made in the southern end of Copley Marsh, one-half mile west of New Portage, in which the drift was found to have a thickness of nearly 400 feet, and the rock floor an altitude about as low as the surface of Lake Erie. The boring is on a tributary of Tuscarawas River, and therefore south of the present continental divide. However, a broad lowland tract, deeply filled with drift, leads from it northward to the Cuyahoga Valley, indicating that this deep channel once had a northward discharge. Borings, though not numerous, are sufficient to indicate that the rock floor of the Cuyahoga has been cut to a very low level, and the valley may have been an outlet for some of the northern Ohio drainage, as already discussed in Chapter III.

In the Tuscarawas Valley at Clinton, near the inner margin of this morainic system, several flowing wells have been obtained from the drift. They are on low ground near the Ohio canal, and but a few feet above the level of the river. Their depth is 35 to 40 feet, and water rises about 5 feet above the level of the canal. They are mainly through blue silt, which is described by the well owners to be putty-like and free from grit. The water is obtained from an underlying gravel bed. There are several wells between Clinton and New Portage which penetrate a similar blue silt and obtain water from gravel beneath it, but the water does not overflow. On Charles Harmon's land, in the Tuscarawas Valley near Mud Lake below Clinton, is a boring which struck rock at 80 feet, but this is a remarkably shallow depth to rock.

At Canal Fulton, which is situated in the midst of the moraine, rock is exposed in the west bluff to a considerable height above the Tuscarawas River, but on the east side of the river wells 60 to 80 feet deep do not reach rock. In these wells a small amount of blue till is struck, but the material is mainly sand and gravel.

Newberry has made the following statements concerning the drift in the Tuscarawas Valley below Canal Fulton:[1]

From Fulton to Millport and thence to Massillon many borings have been made, and in these where the course of the auger was not arrested by bowlders the drift

[1] Geology of Ohio, Vol. III, pp. 152–153.

deposits have often been found to be more than 100 feet in thickness. For example, two wells were bored by Mr. E. Roberts northeast of Millport. In one the gravel was penetrated to a depth of 84 feet without reaching the rock; in the other, it was found to be 97 feet in thickness. On the farm of General Beatty two wells were sunk for water within 100 yards of each other. One reached rock at about 50 feet; the other, more westerly, is 100 feet deep, all drift. At the Charity School, as I heard from the Hon. A. C. Wales, a well was sunk to a depth of 90 feet through beds of sand and gravel without reaching rock. An interesting fact connected with this well is that near the bottom logs of coniferous wood, apparently cedar, were taken out.

THE SHOULDER OF THE SCIOTO LOBE.

On the uplands west from Canal Fulton, near Fox Lake, the drift has a known thickness of 80 feet at H. Meibert's wells, and 60 to 80 feet in several wells at farmhouses 1 to 2 miles west of Fox Lake. Southward the uplands are more thinly coated, and many hills and ridges in the vicinity of Fairview, Dalton, West Lebanon, and Mount Eaton afford numerous outcrops of rock on their slopes and summits. The valleys are, however, filled deeply with drift and contain morainic features. In passing from these valleys eastward to the Tuscarawas Valley one finds considerable increase in the amount of drift on the uplands.

At Beach City, near the outer border of the moraine, but within its limits, borings in Sugar Creek Valley strike rock at 90 to 110 feet, the drift being mainly assorted material. A boring at Nathan Rose's farm, $1\frac{1}{4}$ miles southeast of Beach City, penetrated 88 feet of drift, a portion of which is cemented gravel. It is situated on the gravel plain which heads in the moraine at Beach City. In the vicinity of Wilmot several coal shafts have been sunk. Of these the drift in Putnam's shaft is 43 feet, in Wyandot's 71 feet, and in Hurrah's 56 feet. The thickness of drift on the hills and ridges from Sugar Creek westward to Killbuck Creek probably averages less than 25 feet, but in the lowlands it is so thick that ordinary wells seldom reach its bottom.

It was in one of these lowland tracts, in eastern Holmes County, that the skeleton of a megalonyx was discovered, described by Claypole.[1] It was found in a marsh beneath a bed of peat 6 feet in thickness and on a bed of shell marl. Such marshes are not uncommon along this morainic belt, but are a less prominent feature than in the interlobate tract.

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[1] Am. Geologist. February, 1891.

In the comparatively low tracts that lead back into hilly districts along the glacial boundary in Holmes County the till is underlain by fine calcareous sand or silt of blue and yellow colors, like that in the Cuyahoga Valley near Akron. Wherever this silt was noted the drainage is northward from the unglaciated toward the glaciated tract. This situation makes it probable that the silt in question was deposited in small glacial foot lakes formed in advance of the ice sheet. These were subsequently invaded by the ice sheet, which filled the place the lakes had held and deposited till upon the silts. An excellent exposure showing several feet of silt may be seen on the Weinsburg and Berlin road, about a mile northeast of Berlin.

On the elevation where Berlin stands there is scarcely any drift, but a mile east or west from this village on lower land it attains considerable thickness. John Miller, 1 mile west of Berlin, has a well 45 feet deep, and his neighbor, Chalmers Sharlock, one 40 feet deep which did not reach rock. These wells are within a mile north of the southern margin of the well-defined drift, if not of the glacial boundary.

At Millersburg rock is struck in the vicinity of the court-house at about 75 feet, which gives the rock surface an altitude slightly below the bed of Killbuck Creek. Drift exposures of considerable extent occur in the north part of Millersburg, along the east side of the Cleveland, Akron and Columbus Railway. There is a small amount of ordinary pebbly till, but the great bulk of the drift is a poorly assorted gravelly sand with a slight clayey admixture. Where stratification is traceable the beds are horizontal, with considerable cross bedding, but arching or contorted beds were not observed.

No records of wells of sufficient depth to show the thickness of the drift were obtained along Killbuck Valley, between Millersburg and Wooster. At Wooster the drift is thin on the slopes of the valleys, and a well in the village, two blocks south of the court-house, struck rock at 40 feet. The breadth of the valley bottom in the vicinity of Wooster is such, however, that a channel of considerable size may be concealed in it. J. H. Todd, of Wooster, has furnished the writer with records obtained in the vicinity of that city, which in some cases extend to a depth of about 100 feet without reaching rock, while on neighboring hills the rock rises 200 feet above the well mouths.

Between Killbuck Creek and Lake Fork the uplands carry compara-

tively thin deposits of drift, there being numerous outcrops of sandstone on the large ridges. The thickness probably averaged no more than 25 feet; but an abandoned valley connecting the streams along the line of the Pittsburg, Fort Wayne and Chicago Railway is deeply filled with drift, wells having reached a depth of 185 feet without entering rock (Todd).

Along Lake Fork the terraces fill the valleys in places to a height of fully 100 feet above the present stream, and it is not improbable that the drift extends considerably below the present stream bed. A gas-well boring at Loudonville with about 150 feet of drift, entered rock at an altitude fully 50 feet lower than that of the bed of the creek at its nearest approach to the village. The drift consists of gravel at surface, while sand constitutes the main part of the section. A boring for water at Peter Long's, in Loudonville, penetrated 125 feet of drift without entering rock.

In the vicinity of Perrysville the drift is heavy, but no records of deep wells were found to show its full depth. There are knolls 50 feet or more in height, and the crest of the moraine south of the village rises about 150 feet above the level of Black Fork. It is probable that the thickness is even greater than the height of the moraine above the creek. In a tributary of Black Fork, 3 miles north of Perrysville, a well at Mr. George Hay's penetrated 150 feet of drift without reaching rock, and George Maurer's well, on the adjoining farm, strikes no rock, though 115 feet deep. Near the northern end of the reentrant portion of the moraine north of Mansfield, a well in Black Fork Valley, at David Forkler's, penetrated 180 feet of drift without reaching rock. In the lowland tract in the north part of Mansfield a gas-well boring penetrated 250 feet of drift, striking rock at an altitude about 900 feet above tide. The waterworks plant in this lowland has several wells 100 to 140 feet in depth, some of which reach rock. In the business portion of Mansfield, on the slope north of the public square, there are outcrops of rock at an altitude of about 1,200 feet. Many of the ridges and hills in the vicinity of Mansfield have but a small amount of drift, though all seem to have been glaciated.

THE EASTERN LIMB OF THE MAIN LOBE.

At Lexington, in the valley of Clear Fork, near the outer border of the moraine, wells 100 feet deep do not reach the bottom of the drift, but on the bordering uplands the general thickness is only 30 or 40 feet. The highland tract in southern Richland County was crossed by the writer

along the line leading direct from Mansfield to Fredericktown, and a coating of drift 10 to 20 feet thick was found to be quite generally prevalent. On a prominent point about 3 miles north of Bellville, and perhaps 1,450 feet above tide, a well at Mr. Shickler's reached rock at 18 feet, and on points about the same altitude, south of Bellville, wells penetrate several feet of drift. One-half mile north of Palmyra, on comparatively low ground, a well at C. Snyder's, 67 feet deep, penetrated considerable till and entered gravel near the bottom South from Palmyra the drift is much thicker than it is to the north. Passing west to the less elevated country the thickness of the drift increases, and where morainic features set in near Darlington it is generally 50 to 60 feet, or even more, in depth. G. McFerrins's well, near Darlington, has a depth of 61 feet without reaching rock. It penetrates much till.

In Fredericktown rock is exposed along the east side of Owl Creek, and the creek here crosses a rocky point which extends westward slightly beyond the railroad track, making a rock cut necessary south of the station. Mr. Cummings's well in the village, at a level about 60 feet above the station, struck no rock at a depth of 80 feet; but just east of this well, on equally elevated ground, overlooking Owl Creek, Wesley Whitford has a well which struck rock at 25 or 30 feet. The wells in Fredericktown usually obtain water at about 40 feet from beds of gravel between till sheets.

For several miles west of Fredericktown the preglacial ridges and valleys are quite effectually concealed by heavy deposits of drift, but from Fredericktown eastward the drift sheet is thin, its general thickness being not over 25 feet. It maintains a nearly continuous sheet up to the very border of the neck of apparently driftless land, that has already been described as leading from Independence eastward to Mohican Creek.

In the village of Jelloway, which is near the south border of this neck, flowing wells have been obtained from the drift at a depth of about 40 feet; and at Mr. Richert's, 2 miles west of Jelloway, a flowing well 50 feet deep was obtained without reaching rock, while a well on higher ground at his residence struck rock at 50 feet. These wells are practically at the border of the nearly driftless neck, there being scarely any drift on the uplands north of Mr. Richert's or at Jelloway. They are, however, in valleys, and show a larger amount of drift than the uplands adjacent to them. The drift penetrated in these flowing wells is said to be a pebbly blue clay.

East of Danville, at the point where Wright located the glacial boundary, the Cleveland, Akron and Columbus Railway cuts through morainic accumulations to a depth of 36 feet without reaching rock. In Danville a well is reported by Wright, on the authority of A. J. Workman, to have penetrated 136 feet of drift, "passing through yellow clay, blue clay, gravel, quicksand, and cemented gravel, and still not reaching rock." Another well in Danville, 65 feet deep and through similar material, was reported.

On the uplands between this outer member of the morainic system and Mount Vernon there is but little drift compared with the amount in the main moraine west of Mount Vernon.

In the valley of Owl Creek, near Gambier, the following section of the bluff of the stream is reported by Read:[1]

Section of Owl Creek Bluff, near Gambier, Ohio.

	Feet.
1. Yellow clay, with drift bowlders and pebbles and many flat fragments of local rock	8
2. Blue bowlder clay, unstratified, with rounded granitic bowlders, gravel, and angular fragments of local rocks	20
3. Laminated blue clay	3
4. Coarse stratified gravel	4
5. Coarse stratified sand	2
6. Yellow laminated clay	2
7. Blue laminated clay	2
8. Unstratified bowlder clay	4
9. Stratified sand and gravel	8

In an exposure on Grannys Creek, a few miles northeast of Mount Vernon, a section of bowlder clay fully 60 feet in height is extensively exposed. In this section the surface oxidation extends only 8 to 10 feet, the clay below being blue.

At Mount Vernon a large number of borings have been made in the valley of Owl Creek for the purpose of obtaining flowing wells. At the time of the writer's visit to the city, in June, 1890, fully 100 successful flows had been obtained. The depth of the wells ranges from 63 to 97 feet. Isaac Lafever, of Chicago Junction, Ohio, who made many of these wells, states that they penetrate about 45 feet of loose gravel and sand, at which depth a blue clay is struck which extends to the water vein. No statistics were obtained as to the rate of flow or to the height to which the water will rise above the surface. The flow is strong from a height of 2 or 3 feet

[1] Geology of Ohio, Vol. III, 1878, p. 332.

above the surface. Mount Vernon derives its water supply almost entirely from these flowing wells.

Several attempts to obtain natural gas have been made in and about Mount Vernon, and the borings show much variation in the thickness of the drift. The writer is indebted to A. D. Bunn, of Mount Vernon, for statistics concerning the drift penetrated. A boring at the waterworks, on ground about the same altitude as the Baltimore and Ohio station (991 feet), struck rock at 224 feet. The drift is mainly sand and gravel. This well is known as the Power-house well. About 2,000 feet south-southwest of the power-house well, and at about the same level, 234 feet of drift was penetrated. In the northern part of the city, on ground perhaps 100 feet higher than the station, a well, known as the Banning well, penetrated 90 feet of drift, mainly sand and gravel. A boring at the railway crossing in the west part of Mount Vernon penetrated only 90 feet of drift. About a mile east-northeast from the railway station, in a tributary of Owl Creek, where the altitude is about the same as at the station, only 8 feet of drift was penetrated. Two and one-half miles northeast of the central part of Mount Vernon a well called the Simpkins well penetrated 90 feet of drift. Its mouth has an altitude about 100 feet above the station. A well made many years ago at the court-house is reported by William McClelland, of Mount Vernon, to have obtained water in gravel at a depth of 75 feet, after penetrating much blue clay.

At Bangs station, 4 miles west of Mount Vernon, several flowing wells have been obtained on ground having about the same elevation as the station, 1,102 feet. Their depth is 40 to 45 feet, and when first struck water would rise 20 to 22 feet above the surface. A well at Samuel Finnerty's, on somewhat higher ground, has a depth of 74 feet. In all these wells there is till above the water vein. The source of the water supply is probably from adjacent upland tracts, whose altitude is 150 feet or more above the wells.

On the elevated tract along the inner member of the morainic system in western Knox County the drift is so thick that rock is rarely struck in wells, and scarcely an outcrop of rock occurs in ravines. The appearance of the surface supports the conclusion that the hills and ridges have a drift mantle 100 feet or more in thickness, while buried valleys have 400 feet or more. W. G. Tight reports that a well at Homer, in northeastern Licking County, passed through 400 feet of drift. J. M. McFarland's well, on an elevated tract at Appleton, has a depth of 167 feet and does not strike

rock. The drift is gray clay with thin beds of sand. W. H. Wood's well, near Locke, has a depth of 123 feet without reaching rock. This well is in a slightly depressed portion of the uplands, and was made for the purpose of obtaining a flow. Eleven water-bearing beds were passed through, but water does not overflow from any of these beds. It stands, however, within 11 feet of the surface. An ocher-like bed was struck at the depth of 105 feet, whose material was so fine that it would not completely settle in water in forty-eight hours.

At Hartford wells are only 20 to 40 feet deep, there being at these depths an abundant water supply from sand beneath beds of till.

In Utica, in the valley of Licking River, a well at Levi Knowlton's penetrated 58 feet of drift, mainly till, without reaching rock. Two miles north of Utica, at R. S Tullos's, a flowing well on comparatively low ground terminates in drift at 85 feet. The drift is mainly till. On the uplands east of Utica wells in the morainic area penetrate 25 to 40 feet or more of drift.

At Newark several borings for natural gas have been made, in some of which a large amount of drift was penetrated, in one instance 235 feet, in another 189 feet, and in another 147 feet. They are all in the Licking Valley, at about the same altitude as the Baltimore and Ohio station (819 feet). The drift is principally sand, but some clay appears in the surface portions. In the northern part of the city, wells penetrate from 3 to 6 feet of hard clay before entering the gravel. Exposures of till are numerous in the south bluff of Licking River, in the eastern part of the city, up to a height of about 60 feet above the stream. Bordering Newark on the northeast, as above noted, is a lowland tract, standing about 100 feet above the Licking River, which has considerable till in it. There is also sand, suitable for molders' use, and gravel, the latter being sometimes disposed in arched and distorted beds.

West from Newark, on the main moraine, the drift has a thickness of 50 to 75 feet or more on the uplands and is probably much thicker in the principal valleys. J. C. Wilcox's well, at his residence near Kirkersville, on a very prominent part of the uplands, is 70 feet deep and does not strike rock. Near Etna several wells have a depth of 50 feet without reaching rock, and a boring made some years ago about a mile east of the village was thought to have gone to a depth of 183 feet without reaching rock, the information being given from memory.

At William Watson's, on the south border of the Licking reservoir, a gas-well boring penetrated 150 feet of drift. It is on ground perhaps 100 feet above the level of the reservoir. Rock is exposed on Mr. Watson's farm at levels still higher than the well mouth.

A series of gas wells on Little Walnut Creek show a large amount of drift along its valley from near the source of the stream to Canal Winchester, near which it enters the Scioto Valley. The writer's notes were obtained from the well drillers or officers of the gas companies soon after the borings were made, and therefore represent quite accurately the thickness of drift. The structure of the drift was not so well observed, but a few apparently accurate records will be presented.

A well at the border of the canal, between Baltimore and Basil, whose mouth is about 850 feet above tide, has 302 feet of drift. Its drift section, as given by the driller, J. H. Taylor, of Louisville, Ohio, is as follows:

Section of drift beds in a gas boring near Basil, Ohio.

	Feet.
1. "Common clay" (till?)	8
2. Coarse gravel	12
3. Fine quicksand	110
4. Gravel	40
5. Sand	128
6. Blue clay, extending to Berea grit	4
Total drift	302

Gas well No 1, at Hadley Junction, is reported by the driller, Frank Hugaboom, of Pleasantville, Ohio, to have penetrated 335 feet of drift. The altitude of the well mouth is 883 feet above tide, making the rock floor only 548 feet. The same driller reports that a well just east of the village, on ground about 900 feet above tide, penetrated 148 feet, and another near by only 45 feet of drift, while on much higher ground a mile or so east of Hadley rock is struck at about 30 feet. Hadley Junction is therefore near the east border of the valley. The deep valley extends south a couple of miles from Hadley before swinging westward. Wells near its southern border are reported by Mr. Hugaboom to have the following amounts of drift: The Lamb well, 1 mile west of Pleasantville, 225 feet; Levi Hite's well, $1\frac{1}{4}$ miles west of Pleasantville, 326 feet; a well near Mr. Hite's (owner's name not learned), 360 feet; the Watson well, near Hite's, 225 feet. In all the wells reported by Mr. Hugaboom the main part of the till is within 50

feet of the surface. Below this depth the drift is principally sand. At Carroll a gas boring was reported by a citizen to have passed through 264 feet of drift. The altitude of the well mouth is 835 feet, making the rock surface 561 feet above tide. The upper 15 feet is till, the remainder mainly quicksand, though some gravel occurs. In a boring at Canal Winchester, reported by the treasurer of the natural gas company, 216 feet of drift was penetrated. The altitude of the well mouth is 769 feet, making the rock floor 553 feet. The greater part of the drift is quicksand. This well boring is one-half mile north of Little Walnut Creek. Along the creek near Canal Winchester there are outcrops of shale, and 2 miles south of it, at Lithopolis, rock rises to an altitude 200 feet or more above the level of the mouth of the gas well, or nearly 1,000 feet above tide as indicated by the East Columbus topographic sheet.

At Lancaster several gas wells show a large amount of drift. The following notes were obtained from Mr. Slocum, a citizen of Lancaster, who kept careful records of the wells. The altitude of the majority of the well mouths does not differ greatly from that of the railway station, 841 feet.

Well No. 1, at the north side of the canal and west side of Maple street, altitude about 825 feet, penetrated 131 feet of drift, entirely sand and gravel; a log was struck at 26 to 27 feet. Well No. 2, just east of the canal reservoir and about 50 feet above it (870 feet above tide), penetrated 60 feet of drift. Wells Nos. 3, 4, and 5 start on the sandstone which is at the surface in the east part of the city. Well No. 6, on the Fair ground, penetrated 180 feet of drift; a log was struck at about 100 feet; altitude of well mouth about 850 feet. Well No. 7, at Forest Rose cemetery, penetrated but little drift. Well No. 8, in northwest part of the city, passed through 180 feet of drift; altitude of well mouth about 840 feet. Well No. 9, near center of city, south of King street, has 180 feet of drift; altitude about 840 feet. Well No. 10, east of center of city and north of Main street, has about 180 feet of drift; altitude about 840 feet. There are several others not made by the city, each of which has 130 feet or more of drift.

As above noted (p. 269), there is in Lancaster a drift ridge, upon which the court-house stands, containing much cemented gravel which has the appearance of having suffered considerable erosion and leaching prior to

the Wisconsin stage of glaciation. In the deeper part of the valley, also, the drift is probably of pre-Wisconsin age.

Wright reports a well on a range of hills north of Clear Fork, at an altitude about 350 feet above the Hocking Valley, to have penetrated 40 feet of till, and another 20 feet. West of this range of hills, at Amanda, a gas-well boring at the flour mill near the station passed through 60 feet of drift, mainly till The altitude here is but 100 feet above the Hocking Valley at Lancaster (933 feet above tide). In portions of the village rock is struck at 10 feet or less. West from Amanda, on the divide, at an altitude 150 feet above the station, the drift is shown by wells to be in places 60 feet thick. Mr. Stout has a well 62 feet deep, mainly till, that does not reach rock. There are outcrops, however, between Stout's well and Amanda, where the rock surface has an altitude but 25 feet lower than that of the well mouth at his residence. A well at John Crumley's, 3 miles west of Lancaster, on comparatively low ground near Hunters Run, penetrated 78 feet of sand and gravel and did not reach rock. At D. Crumley's, on the Circleville and Lancaster pike, about 3 miles west of Lancaster, a well has 39 feet of drift, the upper 18 feet being yellow till, the remainder sand. Near Crumley's bold ledges of sandstone rise to a height of 125 feet above the well mouth, on whose surface there is scarcely any drift. A similar isolated sandstone ledge in Lancaster, called Mount Pleasant, carries scarcely any drift, aside from bowlders.

On the uplands south of Circleville, near Thatcher, the drift is very thin compared with its thickness east and northeast of Circleville, the difference being due mainly to the absence of the inner or main member of the morainic system on the uplands southeast of the city and its presence on those east and northeast.

In the Scioto Valley at Circleville two gas-well borings passed through a large amount of drift, one in the west part of the city having penetrated 140 feet, and one on slightly higher ground, in the eastern part of the city, 187 feet. The rock floor is 520 and 540 feet above tide in the two borings, the lower altitude being at the east well. In the west boring the drift is mainly gravel, but in the east boring there was a thin bed of gravel at the surface, apparently belonging to the outwash from the moraine, below which there was a heavy bed of blue till.

In a sewer excavation on Pickaway street, between Franklin and Mound streets, the following section was obtained:

Section in a sewer ditch in Circleville, Ohio.

	Feet.
1. Clay and clayey gravel of dark-brown color	$2\frac{1}{2}$–3
2. Gravel, horizontally bedded, containing many cobblestones, but in places composed only of fine sand	4–6
3. Yellow till, with streaks of blue till, the whole being calcareous from the very top, showing either that leaching had not occurred before the deposition of gravel, or that the calcareous element was restored	5–6
4. Blue till exposed near bottom of sewer	1–2

In the till there are many small pockets of fine gravel. They are elongated horizontally, though they do not lie perfectly horizontal, their inclination being in some cases as great as 25°. The pebbles in the till and also in the overlying gravel are mainly limestone. The gravel deposits capping the till are probably of the same age as the morainic hills east and north of the city, while the till may be slightly older. Its calcareousness at surface indicates either that no great amount of leaching had taken place before the gravel was deposited on it, or that, leaching having occurred, calcareous material was restored to it from the overlying calcareous gravels, or possibly the glacial stream that deposited the gravel.

In a gravel pit in a morainic knoll one-half mile north of Circleville, some pebbles were collected and classified with the following results. The size determined upon included only pebbles an inch or less in diameter:

Pebbles in a gravel pit near Circleville, Ohio.

Limestone	126
Shale	6
Quartz	1
Chert	5
Granite	4
Other Archean pebbles	4
Total	146

The pebbles are nearly all rounded and show no striæ. Many nodules of clay, ironstone, and fragments of shale several inches in diameter occur in the pit. They are probably of Devonian age. There are cobblestones and bowlderets of limestone up to a foot in diameter. The stratification is nearly horizontal, but is subject to occasional abrupt departures from the horizontal.

In a morainic tract west of Kingston a sharp ridge with north-south

trend is opened by a road crossing it, which gives an excellent section 20 feet deep at the crest of the ridge. In the lower 10 or 12 feet there is a gravel of medium coarseness interbedded with fine gravel. All of the beds arch with the surface of the ridge. Above these beds, occupying the summit and western slope of the ridge, are beds of coarser gravel which dip with the slope of the ridge westward at an angle of about 30°. The lower layers extend slightly beyond the summit of the ridge and rest upon the truncated ends of beds of fine gravel that dip eastward. Near the base of the west side of the ridge the gravel beds change somewhat abruptly to till.

No records of deep borings were obtained along the Scioto Valley below Circleville. A deep gas-well boring in Chillicothe begins in rock, being at the base of a rock ledge. The drift is said to be about 100 feet thick in a gas boring near the bend of the Scioto at Richmonddale, a few miles southeast of Chillicothe, but the exact amount was not ascertained, nor was the altitude of the well mouth. The Scioto Valley has probably been filled with drift to a depth of 100 to 200 feet along much of the course between Columbus and the glacial boundary.

THE WESTERN LIMB OF THE MAIN LOBE.

On the comparatively low upland west of the Scioto, at Anderson, a well at Mr. Langdon's penetrated 60 feet of drift. At Mr. Steel's, near Anderson station, in North Paint Valley, wells 32 feet deep obtain water in gravel. On the elevated upland east of Lattas a well at Mr. McConnell's is reported by Wright to have "passed through 12 feet of yellow clay and 5 feet of gravel. About 13 feet from the top a piece of wood 3 to 4 feet long and 3 inches through was found in clay. From this point the eye surveys a vast extent of till in the valley of North Fork of Paint, which is about 400 feet lower." At several houses near McConnell's, wells are reported to have penetrated 25 feet or more of yellow and blue till before reaching rock. In the valley of North Paint Creek, near Austin, there is a till exposure fully 50 feet high, yellow for a few feet at top, the remainder of blue color. This valley has but little gravel above Frankfort, but below that village it carries a comparatively level gravel plain.

About midway between Lattas and Greenfield are several wells along the Greenfield and Chillicothe pike which show considerable drift. At

W. E. Parrott's 60 feet and at William Stinson's 44 feet were penetrated without reaching rock, and other wells show 30 feet or more.

Near Spout Spring station, midway between Greenfield and Bainbridge, there are exposures of horizontally bedded, well assorted drift, 100 feet or more in thickness, some of the alternating beds being of fine sand and others of coarse cobble. Large masses of cemented gravel and cobble occur at different horizons from the base to within 30 feet of the top. The pebbles are composed largely of the local shales, but limestone and sandstone pebbles and Canadian crystallines are not rare. The elevated hills in that vicinity are very thinly coated with drift, but along Paint and Buckskin creeks it is in many places 100 to 150 feet thick, filling up the valleys and resting on the slopes.

At Greenfield drift exposures in the west bluff of Paint Creek show 50 feet of till, but a short distance west, on higher ground, rock is near the surface.

In the several members of the morainic system, from Ross and Highland counties northward to the combined moraine in Clark County, the general thickness of the drift falls between 50 and 100 feet, there being, as a rule, 20 to 30 feet more of drift in the morainic tracts than on the bordering plains. The following represent the more important well records collected: Josiah Hopkins's well, in the fourth or inner member, a few miles east of Washington, passes through 70 feet of till and does not reach rock. At Washington the gas well penetrates 70 feet of drift, mainly till. B. F. Coffman's well, in the south part of the village, penetrates 60 feet of till. At Milledgeville the flouring mill well, 70 feet in depth, does not reach rock.

Wells in Jamestown enter rock at about 12 feet, but the moraine near Jamestown rises about 50 feet above the altitude of the village, and it is probable that the drift has a corresponding increase in thickness.

At South Solon a well at Harrod's drug store, 187 feet in depth, penetrates 140 feet of drift, largely till. At A. Gorden's, on the crest of a morainic ridge one-fourth mile west, a well boring 165 feet in depth is thought to have terminated in drift.

At Midway the town well has a depth of 51½ feet through till, and a well at a blacksmith shop has a depth of 54 feet. Neither of them enter the rock

At South Charlestown a well at a saloon north of the Little Miami station does not reach rock at a depth of 75 feet.

In London one gas-well boring penetrates 155 feet and another 200 feet of drift. In both wells the drift is mainly till. A flow of water comes from the rock at a depth of 250 feet. At the waterworks in London there is a strong vein of water in gravel below till at 60 feet and another at about 150 feet.

Chamberlin some years ago called attention to hillocks of angular gravel and disturbed stratification between London and Midway, Ohio.[1] Several other exposures in that vicinity exhibit the phases of gradation from till into gravel, and the angularity of pebbles in the gravel to which Chamberlin called attention, but no other instances of disturbed stratification were observed. From the frequent occurrence of gravel pits it is inferred that nearly all the knolls in the vicinity of London and Midway may contain gravel in their deeper portions, even where the surface is till. Less difficulty is experienced here in obtaining gravel for road ballast than in some of the later moraines of the Scioto lobe. In the morainic system under discussion gravel knolls are sufficiently abundant throughout its entire length to furnish gravel at convenient points for all the pikes.

Two borings for oil near Vienna Cross Roads penetrate 265 and 245 feet of drift, mainly till. One is located 1½ miles east and the other a half mile south of the village, each at an altitude 1,200 feet or more above tide.

At Mechanicsburg a gas boring near the station penetrated 130 feet of drift, and one at Major Baker's, on an elevated drift ridge, penetrated 230 feet, the rock surface being at about the same altitude in both wells, 925 feet, more or less, above tide. In Baker's well the upper 100 feet is a clay with comparatively few pebbles; the remainder is a very pebbly clay with but little sand or gravel interbedded with it. Several wells have been obtained at about 120 feet in the vicinity of this village, in gravel below till.

At Catawba village Eli West has a well 215 feet in depth which did not strike rock. The upper 125 feet was mainly through soft blue till. Beneath this is a harder and more sandy till, which is probably Illinoian. The lower 25 or 30 feet is a soapy clay with few pebbles.

At Fountain Park there are several flowing wells whose depth ranges

[1] Am. Jour. Sci., May, 1884.

from 37 to 98 feet. Each well has about 25 feet of till at the surface, beneath which is sand and gravel. The variations in the depth of the wells is due to the variations in the distance through the sand to a gravel bed coarse enough to be screened by the strainer placed at the bottom of the drive pipe. A gas-well boring at Fountain Park struck rock at 106 feet.

At the railway station in Woodstock a flowing well obtains water from gravel below till at a depth of 50 feet. On the uplands south of Woodstock and Fountain Park rock is struck in places at about 50 feet.

At Cables and west from that village there is a lowland tract crossing the moraine, and near the water parting rock is exposed to a height of 5 or 10 feet above the level of the Columbus and Indianapolis Railway. Above the rock are heavy beds of gravel and cobble which are capped by till. The eastern slope of the morainic belt (both on upland and lowland) carries heavy deposits of till, but the western slope contains much more gravel than till, and the lowlands are underlain extensively by gravel, as indicated by the well sections.

In northeastern Champaign and southeastern Logan counties there are numerous limestone quarries, the rock surface being higher here than it is farther south, and the drift correspondingly thinner. The drift has, however, in many places a thickness of 50 to 75 feet or more.

At Middleburg, near the inner (eastern) border of the morainic system, there are limestone quarries, but in portions of the village, at levels as low as the quarries, wells penetrate 60 to 90 feet of till before reaching rock.

On "Bald Knob," a large gravel hill near the outer border of this moraine, in southern Logan County, a well was sunk many years ago to a depth of 111 feet without obtaining water. It was entirely through coarse gravel and cobble.

On an elevated part of the moraine east of West Liberty, perhaps 200 feet above the station, a well on Jonathan Parker's farm penetrated 194 feet of drift, striking shale at the bottom. A well immediately north of West Liberty, on the upland, penetrated about 170 feet of drift. The altitude is 90 to 100 feet above the railway station, or about 1,200 feet above tide. As noted previously, a gas boring in West Liberty penetrated 216 feet of drift.

At Zanesfield a boring for gas is thought by citizens to have passed through 125 feet of drift, but no reliable record could be found. North of

Zanesfield, near the head of Rush Creek and Mad River (which have a common source in a swampy valley), is a well made by the Buckeye Portland Cement Company, which, as noted on page 366, penetrated 245 feet of drift. The altitude of the well mouth is 1,261 feet above tide. On either side of this valley, in hills that stand 200 to 275 feet above the well, the rock surface is higher than the well mouth, being in places about 1,400 feet above tide. The well was at the border of a marshy lake (now dry) whose length was about 4 miles and breadth three-fourths of a mile. The cement manufactured by this company is obtained from marl beds in this marsh. The cement company made a boring for water three-fourths of a mile north of the gas boring and found no gravel until a depth of 100 feet had been reached, thus showing that the beds beneath the marsh have not a uniform structure.

On elevated ground near the crest of the moraine east of Zanesfield Joseph Outland has two wells which do not reach rock at depths of 50 and 55 feet, water being obtained in gravel below till.

A well at Aaron Taylor's, at the head of Mormon Bottom, on low ground but in line with the crest of the moraine, is 58 feet deep and does not strike rock. From Taylor's farm water flows eastward through Mill Creek to the Scioto and westward to Mad River. The farm is located at the head of Mormon Bottom, a gravel plain leading west to Mad River. One-half mile west from Taylor's, at Nelson Ream's, near the south bluff of Mormon Bottom, rock is struck at 35 feet, and there is a rock quarry only 100 yards south of the well. The deep part of the valley probably lies to the north of Ream's well.

Immediately east from the head of Mormon Bottom, on the inner (eastern) border of the moraine, is the village of East Liberty, which has considerable local notoriety on account of its flowing wells. There are perhaps 100 of them whose depth ranges from 20 to 65 feet. The water is obtained from beds of gravel in the drift. The source of supply is apparently in the higher land immediately to the west, a rapid decrease in head being exhibited in passing toward the east. The water is strongly chalybeate and is in good repute for its medicinal value.

Flowing wells are obtained at many points along the eastern border of the moraine for several miles north from East Liberty, near the headwaters of the several tributaries of Mill Creek. Some of them are but 15

or 20 feet deep. The wells penetrate till until they reach the water-bearing gravel. The variability in depth at East Liberty is due mainly to variations in the altitude of the water-bearing gravel, but in part to the altitude of the well mouth. Outcrops of rock occur along the inner slope of the moraine west of these flowing wells, at altitudes 100 feet or more above them, and the drift is thin for the breadth of a mile or more between these outcrops and the morainic crest. Along the crest of the moraine the drift is so thick that ravines and ordinary wells, which sometimes have a depth of 40 feet, do not reach the rock, and the highest points probably have 100 feet or more of drift. Devonian shales occur to a limited extent beneath the elevated portions of the moraine, but do not seem to form a continuous belt.

The supposed highest point in Ohio, as indicated above (p. 357), lies between this moraine and Bellefontaine at the Hogue Summit on a moraine of the Miami lobe, its altitude being given by F. C. Hill, of the Ohio survey, as 1,540 feet. A point on the moraine under discussion at New Jerusalem is, by aneroid, but 25 feet lower. This great height has been ascribed to the presence of Devonian shales, and Mr. Hill estimated their thickness to be 110 feet beneath the Hogue Summit and 136 feet beneath New Jerusalem. In this estimate due allowance does not seem to have been made for erosion and partial removal of the shale, for, as already noted, 350 feet of drift was penetrated near the Hogue Summit. The most elevated point at which the shale was noted is at New Jerusalem Falls, one-half mile southeast of the village of that name, where its surface is about 100 feet lower than at the New Jerusalem Summit, or 1,415 feet above tide. The shales here have an exposure 60 to 75 feet in height in the gorge below the falls The New Jerusalem Summit is a small drift knoll covering but an acre or two, its highest point being 20 feet or more above the bordering portions of the moraine Its highest point stands about 25 feet higher than the well at Mr. Eastman's, where 350 feet of drift occurs. Attention has already been called to the fact that, were the drift removed from Logan County, the altitude of its highest points would fall 100 feet or more below that of the highest points of the rock strata in southern Richland County, and that even with the increase in height produced by the drift, it is questionable if Logan County contains the highest points in the State.

BOWLDERS.

This morainic system does not have such long-continued distinct belts of bowlders as characterize the equivalent system of the Miami lobe, but it is nevertheless liberally strewn with them throughout the greater part of its course. The number on its surface is markedly greater in the till tracts than where gravel predominates, though not rare in the latter situation. Wright has mentioned some of the larger ones that have been discovered. One at Buck Ridge, west of Canton, measured 55 by 46 by 18 inches. Another, on the bluffs of Tuscarawas River, near Navarre, measured 7 by 5 feet and is 3 feet out of the ground. In section 14, Hardy Township, east of Millersburg, is a bowlder 7 by 5 feet, projecting 3 feet above the surface. Near Oak Grove Nursery, west of Millersburg, at an altitude 430 feet above Killbuck Creek, is a granite bowlder $10\frac{1}{3}$ by $6\frac{1}{2}$ feet, projecting $3\frac{1}{2}$ feet above the ground. In the valley of Baldwins Run, between Lancaster and Pleasantville, a granite bowlder, mentioned by Andrews, of the Ohio survey, as well as by Wright, measures 18 by 12 feet, 6 feet out of the ground. It is described as hornblendic in character. In section 14, Colerain Township, Ross County, near the residence of Isaac De Long, Wright reports several bowlders 6 by 8 feet in diameter. At D. H. Pricer's, on an elevated upland north of Bainbridge (altitude about 550 feet above Paint Creek Valley), a bowlder of hornblendic rock 5 by 3 by 2 feet is reported.

Bowlders of the sizes mentioned by Wright are exceptional, the great majority being but 1 to 3 feet in diameter. They are mainly Archean rocks except at the border of the drift, where there are in many places masses of local rocks which have been transported short distances by the ice sheet and mingled with material derived from greater distances. Many such local bowlders occur along the border of the shoulder east of Mansfield. The largest ones of which measurements were taken are on Adam Berry's and John Ferguson's land, about $1\frac{1}{2}$ miles northwest of Newville. A reddish sandstone is represented by several bowlders 15 feet or more in greatest diameter, whose thickness is 5 or 6 feet. A white sandstone bowlder was found to measure 14 by 24 feet, and stands 3 feet out of ground; another is 18 feet square and has been quarried down nearly to the ground; another, near by, dips into the hillside at an angle of 45°. It was originally large, but has been reduced greatly by quarrying.

There are certain bowlders found in this region which are of great

importance because of their bearing on the question of changes of ice currents. Newberry reports "huge bowlders of Corniferous limestone" in Northampton Township, Summit County, which he thinks have been brought from the islands in Lake Erie.[1] If so, the early ice movements across these islands must have been southeastward—a very different course from that of the later movements. Bowlders of the same class were reported to the writer from Talmadge Township (which is southeast of Northampton), but they were long ago burned for lime. The source of these bowlders should be more conclusively demonstrated before inferences are drawn as to changes of ice currents.

It has been reported by Whittlesey that copper occurs in the drift as far east as Weymouth, Medina County, Ohio.[2]

Bowlders of red, jaspery conglomerate, thought to be from the Huronian rocks north of Georgian Bay, are not rare in the vicinity of Mansfield and northward from there to Norwalk and Brownhelm, and they are occasionally found still farther east, one being reported near Andover, Ohio. They are quite common in western Ohio, northern Kentucky, and Indiana, and a few have been found as far west as southeastern Iowa. Those near the eastern limit of their known distribution indicate a transportation in a direction slightly east of south, though their main distribution appears to have been west of south. Chamberlin and Salisbury have cited the following evidences of southward movement into Ohio from the Huron Basin:

> To the east of the Lake Michigan trough lay the capacious valley of Lake Huron, flanked by Georgian Bay. There is strong evidence that these valleys directed these glacial streams southward in the retiring stages of glaciation, at least, and presumably at all stages. This is shown both by striation and by transportation. Copper, presumed to come from the Lake Superior region, has been found in eastern Michigan and even in Ohio. In the remarkable bowlder belt of Logan, Champaign, Miami, Montgomery, and Preble counties, Ohio, and Wayne and Randolph counties, Ind., are numerous peculiar greenish quartzite bowlders not common to the general drift. Professor Irving has identified specimens of these as derivations from certain quartzites of the typical Huronian region north of Lake Huron, samples in his collection being indistinguishable from the erratics collected by one of us. While it is possible that both the native copper and these quartzites may have had an origin farther eastward, these instances, taken in connection with a wider class of evidence,

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[1] Geology of Ohio, Vol. I, 1873, p. 206.

[2] Smithsonian Contributions, 1866, On Fresh Water Glacial Drift, etc., p. 11.

leave little room for doubt that the basin of Lake Huron determined a southerly movement of the ice current, and thereby rendered collateral aid to the Michigan Basin in directing the broad stream east of the unglaciated island.[1]

A movement to the east of south from the region north of Lake Huron is also shown by striæ to have taken place at some time during the Glacial epoch, there being striæ with southeastward bearing south of Georgian Bay and southeast of Lake Huron, while the majority of those north of Lake Huron bear southward. The evidence from striæ, therefore, supports rather than antagonizes the evidence from bowlders that there were southward movements over western Ohio at some time during the Glacial epoch. The later movements, however, seem to have been southwestward through the Lake Erie Basin, and thence southward into central Ohio, with lateral movement toward the southeast on the eastern side of the Scioto lobe.

STRIÆ.

In the following table are arranged all the published as well as the unpublished observations of striæ pertaining to the Scioto lobe so far as known to the writer. The striæ all appear on the map of the Scioto lobe (Pl. XIII), where their relations to moraines may be readily seen.

Table of striæ in the Scioto lobe.

Location.	Bearing.	Observer.
Hampden, Geauga County, 1 mile south of	N. to S	Leverett.
Hampden Township, Geauga County	S. 15° E. to S. 10° W	Read.
Chardon	S. 10° E	Read.
Chardon, 2 miles southeast of	N. to S. and S. 5° W	Leverett.
Chardon, 2 miles south of	S. 5° W	Leverett.
Chardon, 4 miles south of	S. 5° W	Leverett.
Newberry Township, Geauga County	S. 50° E	Read.
Chester Township, Geauga County	S. 70° E	Read.
Russell Township, Geauga County	S. 50° E. to S. 70° E	Read.
Russell Center, 1 mile southeast of	S. 35° E. to S. 55° E	Leverett.
Bainbridge Township, Geauga County	S. 49° E	Whittlesey.
Mantua Township, Portage County	S. 30° E. to S. 40° E	Whittlesey.
Solon Township, Cuyahoga County	S. 45° E	Whittlesey.
Solon Center, 1 mile north of	S. 20° E	Leverett.
South Euclid, Cuyahoga County	S. 45° W	Leverett.
South Euclid, Cuyahoga County	S. 20° E. to S. 25° E	Whittlesey.

[1]Sixth Annual Report U. S. Geol. Survey, pp. 318–319.

Table of striæ in the Scioto lobe—Continued.

Location.	Bearing.	Observer.
Newburg, Cuyahoga County	N. to S.	Whittlesey.
Peninsula, Summit County	S. 10° E. to S. 20° E.	Leverett.
Twinsburg, Summit County	S. 30° E. to S. 45° E.	Leverett.
Boston Ledges, Summit County	W. to E.	Read.
Boston Ledges, Summit County	S. 30° E. to S. 45° E.	Read.
Hudson Township, Summit County	S. 35° E. to S. 90° E.	Read.
Northampton Township, Summit County	S. 30° E. to S. 60° E.	Whittlesey.
Stowe Township, Summit County	S. 28° E.	Leverett.
Cuyahoga Falls, Summit County	S. 30° E. to S. 45° E.	Leverett.
East Akron (Middlebury), Summit County	W. to E.	Whittlesey.
Talmadge "Coal Hill," Summit County	S. 30° E. to S. 40° E.	Whittlesey.
Independence, Cuyahoga County	S. 20° E.	Whittlesey.
Brighton, 1½ miles south of	N. to S. to S. 10° E.	Leverett.
North Linndale, 2 miles southeast of	S. 5° W. to S. 10° W.	Leverett.
Berea, 2 miles east of	S. 22° W. to S. 34° W.	Leverett.
County line north of Brunswick	N. to S. to S. 30° E.	Leverett.
Portage, near Akron, Summit County	S. 10° E. to S. 35° E.	Read.
New Portage, Summit County, 2 miles north of	S. 40° E.	Leverett.
New Portage, 3 miles southeast of	S. 37° E.	Leverett.
Akron, 2 miles southwest of	N. to S. to S. 20° E.	Leverett.
Copley, Summit County	S. 30° E.	Whittlesey.
Sharon, Medina County, 1 mile southeast of	S. 22° E.	Leverett.
Sharon Township, Medina County	S. 40° E.	Read.
Sharon, 1¼ miles northeast of	S. 30° E. to S. 35° E.	Leverett.
Wadsworth, Summit County, ½ mile east of	S. 20° E. to S. 32° E.	Leverett.
Wadsworth, 1 mile north of	S. 35° E.	Leverett.
Doylestown, Wayne County	S. 40° E.	Leverett.
Doylestown, 1½ miles south of	S. 32° E. to S. 50° E.	Leverett.
Doylestown Township	N. to S.	Whittlesey.
Mount Eaton, Wayne County	S. 40° E. to S. 45° E.	Wooster.
North of Massillon	S. 65° E. to S. 68° E.	Leverett.
Holmesville, 3 miles west of	S. 8° W.	Leverett.
Newville, ½ mile north of	N. to S.	Leverett.
West bluff of Black Fork, 5 miles east of Mansfield	S. 45° E.	Leverett.
Hill north of Windsor station	S. 32° E.	Read.
At schoolhouse, 3 miles northeast of Lexington	S. 10° E. to S. 12° E.	Leverett.
Midway between Mansfield and Lexington	S. 15° E.	Wooster.
West Amherst, Lorain County	S. 30° E.	Leverett.
Henrietta, Lorain County	S. 20° W. to S. 35° W.	Leverett.
Birmingham, Erie County, 2 miles south of	S. 19° W. to S. 77° W.	Leverett.
Townsend Township, Huron County	S. 45° W.	Read.
Sandusky	S. 75° W. to S. 81° W.	Newberry.

Table of striæ in the Scioto lobe—Continued.

Location.	Bearing.	Observer.
Put-in-Bay Island, Lake Erie	S. 15° W. and S. 80° W	Newberry.
Kelleys Island, Lake Erie	S. 60° W. to S. 80° W	Newberry.
Marblehead peninsula	S. 78°	Wright.
Bellevue	S. 65° W	Newberry.
Republic, 4 miles east of	S. 25° W	Leverett.
Genoa, Ottawa County	S. 65° W	Gilbert.
West Sister Island, Lake Erie	S. 80° W	Gilbert.
West Sister Island, Lake Erie	N. to S.	Gilbert.
Findlay	S. 40° W. to S. 45° W	Winchell.
Seneca Township, Seneca County	S. 5° E. and S. 23° W	Winchell.
Crawford, Wyandot County	S. 20° W	Winchell.
Crane Township, Wyandot County	S. 5° W	Winchell.
Grand Prairie Township, Marion County	N. to S.	Winchell.
Marseilles	S. 10° E. to S. 10° W	Winchell.
Richland, Logan County, ½ mile south of	S. 25° W	Leverett.
Belle Center	S. 10° W	Leverett.
Musselman's quarry, near Big Springs	S. 10° W	Leverett.
Big Springs	S. 8° W	Leverett.
Middleburg, Logan County	S. 40° W. to S. 45° W	Leverett.
Delaware	S. 8° E	Leverett.
Quarry east of Jerome	S. 5° W. to S. 12° E	Leverett.
Piersol's quarry, near Jerome	S. 3° E	Leverett.
East bluff of Scioto, west of Powell	S. 16° E	Leverett.
East bluff of Scioto, 7 miles above Columbus	S. 6° E	Leverett.
Columbus, 2 miles west of	S. 20° E	Leverett.
Iberia, 2 miles south of	S. 28° E	Leverett.
Sunbury, Delaware County, 2 miles north of	S. 45° E	Wooster.
Sunbury	S. 45° E	Wooster.
Near Hopewell Church, 2 miles south of Carroll, Fairfield County.	S. 15° W	Leverett.
Near Buckskin station, Ross County	N. to S	Leverett.
Rock Mills, north of Greenfield	S. 30° W	Leverett.
South bluff of Lee Creek, near mouth	S. 12° W	Leverett.
Leesburg, 2 miles southeast of	S. 9° W	Leverett.
Leesburg, 1 mile west of	S. 18° W	Leverett.
Near Leesburg	S. 10° W	Chamberlin.
Near Reesville	S. 45° W. to S. 56° W	Chamberlin.
Conklin's quarry, near New Jasper	N. 73° W	Leverett.
Bickett's quarry, near New Jasper	N. 85° W	Leverett.
Xenia, 4 miles from, on Cæsars Creek	S. 40° W	Leverett.
Near Ogden	S. 37° W	Leverett.
Wilmington, in Lytles Creek Valley	S. 32° W	Leverett.

The general absence of striæ on the numerous outcrops of limestone in the highlands of Logan and Champaign counties has been a cause of surprise, for they abound on either side and north of these highlands at nearly every outcrop examined. An exceptionally careful search was made for them in the highlands, as it was deemed important to gather all possible evidence shedding light upon the direction of ice movement at the junction of the Miami and Scioto lobes. Their absence seems to indicate that the abrasion was less vigorous in the morainic area than it was a few miles back beneath the ice, though the amount of drift deposited there was not less, but instead rather more, than in the region within the morainic system.

South from Champaign County there is scarcely a rock outcrop along the moraine or the inner border plain for a distance of 40 miles or more, which accounts for the lack of observations of striæ in that region. Southwest from this moraine, where the drift is thinner, striæ are found in nearly every exposure examined between it and the outer moraine, and in the district farther west covered by the Miami lobe. The ice movement appears, therefore, to have been vigorous in the terminal portions of the lobe.

The small number of striæ observed near the eastern border of the Scioto lobe and southern border of the shelf or shoulder is probably due in large part to the texture of the rock. The shales in the southeast part of the lobe could scarcely retain striæ long after exposure, as they soon crumble and decay. The coarse sandstone farther north is often of a loose texture, so that striæ could not be preserved. The outcrops of Waverly sandstone are not extensive in the region investigated, and only certain layers of the formation would retain striæ after long exposure.

The large number of striated exposures reported from the vicinity of the Cuyahoga River is due to their remarkably perfect preservation on the Eocarboniferous conglomerate, and that, too, in the most exposed situations, where there has been little or no drift covering the rock since the ice disappeared. The sandstones in that region, being a firm grit rock, are also more suitable for retaining striæ than in the regions farther west and south, where they are soft. The causes for the variation in frequency of observations of striæ in different parts of the lobe embrace, therefore, differences (1) in abrading power of the ice sheet, (2) in concealment by drift, and (3) in the texture of the surface rocks.

INNER BORDER PHENOMENA.

GENERAL FEATURES.

The district here discussed as the inner border tract embraces the portion of the Scioto Basin lying between the inner member of the main morainic system and the Powell moraine, which crosses the basin a few miles north of Columbus. The main part lies south of a line passing east to west about 10 miles north of Columbus, though narrow projections toward the north occur near both the east and the west border of the Scioto Basin, as indicated on Pl. XIII.

This district has lower altitude than border districts. Its lowest part is along the Scioto River, there being a gradual rise from the river, both east and west, to the moraine just described. There is a southward descent along the sides of the Scioto Basin as well as along the stream. The altitude of the river bluff at the border of the Powell moraine north of Columbus is about 875 feet, at Columbus 800 feet, and at Circleville 720 feet. The east and west borders of the basin are about 300 feet higher than the axis followed by the river, and descend southward at about the same rate.

WEAK MORAINES.

The greater part of this district presents a very smooth surface, and portions of it west and southwest of Columbus are known as "the plains." A few quite conspicuous knolls were formed, however, on the east side of the river, and may indicate the position of the ice margin at a stage of halting during the retreat. The position of the larger of these knolls and ridges is indicated on Pl. XIII. A conspicuous group known as the Spangler Hills is found on the east side of the Scioto, about 8 miles south of Columbus. As indicated by the East Columbus topographic sheet, there are two points that rise nearly 100 feet above the border plain. Small knolls appear near this prominent group in a belt about 2 miles long from north to south, and about a half mile in width. They are often sharp and conical, but associated with them are ridges which are more or less winding. The sharpest knolls are gravelly, while those with the gentler slopes contain till. From the north end of this belt northward a mile or more there are low swells inclosing basins 8 or 10 feet in depth. In some cases the basins cover several acres. This gently undulating tract carries a slight coating of till, perhaps 10 feet in thickness, below which there is gravel. The next knoll

of importance toward the north is Baker Hill, on the Groveport pike, 3 miles southeast of Columbus. This rises abruptly about 50 feet above the bordering plain. Its highest point, as shown by the East Columbus topographic sheet, is 819 feet Orton once mentioned to the writer that he had noted evidences of disturbed stratification in it, some of the beds being crumpled and contorted as if by a shove from the ice sheet.

There are no knolls near this hill toward the north, but about 7 miles east of Columbus, in the east bluff of Walnut Creek, a chain of knolls and ridges sets in which is maintained with slight interruptions from there northward for 8 or 9 miles, and possibly may find a continuation in sharp knolls of the same type that lie along the west border of the main moraine from near Hartford northward several miles. The tract east of Columbus includes a sharp knoll at the south, 40 feet or more in height, standing by itself, a short distance north of which a sharp ridge in form somewhat like an esker sets in, which is quite distinct for a mile or more. It is 10 to 20 feet high, and but a few rods wide. It contains much assorted material, but has a slight capping of till, and its surface is liberally strewn with bowlders, features which, taken in connection with its trend, indicate that it is a frontal ridge of morainic character rather than an esker. Between this point and New Albany, which is 8 miles north, a few sharp knolls 20 to 25 feet high, and many lower knolls occur, forming a nearly continuous belt. No knolls of this class were found on a line east from Sunbury to Hartford and northward from that line.

Since the belt does not appear to have a northward continuation from New Albany distinct from the main moraine, there is a probability that it became blended with that moraine. As noted above, there are, from the latitude of Hartford northward for many miles along the west borders of the main moraine, sharp gravelly knolls and ridges, similar to those near Columbus, while the remainder of the moraine is nearly free from such knolls. Quite often some dependence may be placed upon structure in tracing moraines; thus one moraine may be characterized by numerous gravel knolls, while the one next to it in the series may be nearly free from them. While it may not be safe to conclude from this class of evidence that the gravelly knolls in the main moraine are contemporaneous with those in the inner border district and markedly later than the remainder of the moraine, such a tentative classification seems legitimate.

THE PICKERINGTON ESKER.

Besides the knolls and weak moraines above mentioned, there are two well-defined esker ridges in this inner border district which help to give relief to the nearly monotonous plain. One of these is called the Pickerington esker, the other the Circleville esker. The position and trend of each is indicated on Pl. XIII.

The Pickerington esker derives its name from the village of Pickerington, in northwestern Fairfield County, which is situated at its northwest end. The length of this ridge is about 5 miles, its southeastern terminus being in the moraine just west of Basil. It consists of a very small ridge, only 6 to 10 feet high and 4 to 8 rods wide, but it has scarcely a break in it and is a conspicuous feature for one so low. It winds considerably, but has a general west-northwest to east-southeast trend. It is utilized for a wagon road throughout nearly its entire length, and is as dry as a gravel pike. In places the bordering tracts are slightly lower than the adjacent plain and are somewhat boggy, but there is not a well-defined esker trough. In these boggy tracts there is an occasional low knoll of gravel. The southeastern end of the esker does not show a well-marked delta; but there seems to be an equivalent in a greater amount of sand in the moraine than north or south from the esker. The sandy portion of the moraine occupies 2 square miles or more, and seems attributable, in part at least, to the escape of water at the margin of the ice sheet at a time when a portion of the escaping water farther back beneath the ice produced the esker.

At its northwestern end the esker is associated with several drift knolls or short ridges of considerable prominence. The largest one is just east of Pickerington and stands 30 feet or more above the bordering plain. It is one-fourth mile or more in length and about one-eighth of a mile in width. Its trend, like that of the esker, is west-northwest to east-southeast. It is strewn with bowlders that are slightly embedded in a yellow clay that caps the knoll. The nucleus of the knoll is probably sand or gravel. Over an area of perhaps a square mile north, west, and south of this knoll there are knolls 20 feet more or less in height, which give the tract a morainic aspect. The bordering country on all sides is a plain. It is probable that their origin is in some way connected with that of the esker.

The esker itself is made up of gravel and sand of various degrees of

coarseness. On its surface are occasional bowlders, and in places some clay appears as a capping to the gravel and sand. The bordering plains are underlain by till.

THE CIRCLEVILLE ESKER.

The Circleville esker lies along the east side of the Scioto River above Circleville, in places forming its bluffs, while in other places it is a mile from the river. Its general trend is about N. 25° W. to S. 25° E., but for a couple of miles south from South Bloomfield it is nearly north to south. Its length is about 9 miles, but it has several interruptions, as indicated below. At its northern end there is a group of knolls which apparently have some relation to it, but they are much inferior to the esker in size, thus differing from the knolls at the corresponding end of the Pickerington esker, which exceed it in size.

The northernmost ridge of this Circleville esker belt is in section 3, Harrison Township, Pickaway County. The ridge is about a mile long, 100 to 150 yards wide, and is 15 to 50 feet high. The northern third trends about northwest to southeast, but the remainder trends north-northwest to south-southeast, or even more nearly south. At the south end of this ridge and just north of South Bloomfield is a knoll about one-fourth mile long and half as wide, standing in its highest points 20 to 25 feet above the bordering plain. It trends north to south. Both east and west of this one are a few knolls 10 to 15 feet in height. There is then an interruption of the esker for a mile or more; but about a mile south of South Bloomfield a gravel ridge begins abruptly with a height of fully 40 feet, its north end having a slope of 35° to 40°. It is a continuous ridge for 1½ miles, terminating near the mouth of Little Walnut Creek. Its general height is 30 to 40 feet. It consists in places of a central ridge with parallel flanking ridges, connected more or less closely at one or both ends with the main ridge, the width of the system, including flanking ridges, being one-eighth mile, more or less. South from Little Walnut Creek there is a gap of fully a mile, in which no esker ridge appears. Much of this interval is overflow land, and it is possible that the esker was once present, but has been washed away. South of this interval there is a sharp ridge about one-fourth mile long and 30 to 40 feet high in its highest parts. This is succeeded on the south by a gap of about one-half mile. The esker there sets in again and is well developed for fully 4 miles. It

consists of a main ridge that stands 20 to 40 feet above the plain on its eastern border, and 40 to 60 feet above the Scioto River, which flows along its west side. In several places ridges separate from the main ridge and return to it one-fourth mile or so south, making a nearly complete connection with it at each end. In some cases very sharp basins are inclosed between the main ridge and these side ridges. Two were observed that are about 40 feet deep. One of these was dry, the other contained a pond. The ridges on each side have sharp slopes of fully 30°. These slopes afford a means for calculating the amount of filling the basins may have received since the ice retreated. By continuing the slopes downward beneath the basins from opposite sides, they would meet at a point about 20 feet below the present surface, which represents the possible amount of filling. It could not well be greater and it may have been less, especially if the basin originally was somewhat flat in the bottom; but, granting a filling of 20 feet, it follows that the amount is small for such steep slopes of loose material to have contributed, and it affords evidence in favor of the brevity of postglacial time.

At its southern end the esker branches, like the mouths of a stream in a delta, and is lost in a marshy plain. Low ridges or knolls occur in this plain south of the terminus of the esker proper, and on the border of the plain, in the northern part of Circleville, there are gravel knolls which may bear some relation to the esker, though they are situated in the moraine. The termination of the esker proper is but a mile or so from the moraine. In all probability the esker was formed before the ice sheet had withdrawn from the moraine.

But few exposures occur to show the structure of the esker. A well at R. D. Harmon's residence, on the crest of the esker, about 3 miles north of Circleville, penetrated 60 feet of sand and gravel and obtained water at about the level of the Scioto River. The water contains sulphur in such large amount that stock will not drink it. The sulphur is probably from sulphuret of iron contained in fragments of shale. Mr. Stevenson has a well near the base of the ridge, a short distance north of Harmon's, which penetrated 6 or 8 feet of clay and then 30 feet of gravel before obtaining water, probably reaching the level of the Scioto. In places the ridge is capped by a few feet of clay, through which pebbles are scattered, but quite as often the gravel is at the surface. At a slight exposure near

the top of the esker, by the east end of the bridge, 3 miles above Circleville, there is at surface a clayey gravel with a depth of 2 to 3 feet, below which is a series of beds of fine gravel dipping sharply westward with the slope of the ridge. These terminate abruptly like a cross bedding in a layer of cobble, which dips slightly eastward. In an exposure south of South Bloomfield there are cobble beds dipping abruptly southward. This exposure gives only a partial view of the structure. So far as examined the pebbles are largely limestone, but fragments of black shale and granitic rocks are not rare. An interesting feature connected with this esker is its very slight elevation above the Scioto, its base being but 20 to 30 feet above the river bed. The river has, therefore, cut down but a few feet since the Glacial epoch, and that, too, notwithstanding the rapid fall. In the 40 miles (by direct line) from Columbus to Chillicothe the stream falls nearly 100 feet, or about 2 feet per mile if the main deflections of the stream be taken into account. This slight erosion, like that shown by the esker, appears to be strong evidence of the brevity of the postglacial time.

The esker lies in the midst of a gravelly belt through which the Scioto River flows. The width of this belt is about 2 miles in northern Pickaway County, but below the mouth of Little Walnut Creek it expands to a breadth of not less than 4 miles, the expansion being mainly on the western side of the river. This gravelly tract is slightly lower than the bordering till plains and its border is very distinctly marked. With the exception of the esker it stands but 20 to 40 feet above the Scioto River. The esker is slightly higher than the till tracts adjacent to the gravelly belt. This gravelly belt was apparently formed while the ice sheet still covered the region, for the gravel in places carries a thin capping of till. The presence of an esker in its midst is also an evidence of subglacial deposition.

STRUCTURE AND THICKNESS OF THE DRIFT.

With the exception of the valleys of the principal streams and a few small areas on the uplands the surface portion of the drift in this inner border tract is ordinary till. The district may, therefore, be considered a great till plain. On portions of it there are thin deposits of silt or clay which are less pebbly at surface than at a depth of 4 or 5 feet. There does not seem to be a weathered zone or interval between the silty portions and the pebbly till below, but instead the evidence favors the idea that there is a transition upward from pebbly till to clay with but few pebbles.

In the upper 2 or 3 feet there are ordinarily not more than one-fourth as many pebbles as there are 5 or 6 feet below the surface. This is true in the immediate vicinity of the Scioto. At higher levels, near the border of the basin, pebbles are not so scarce. On the contrary, surface bowlders are numerous near the border, while in the central portion they seem to be covered, in places at least, by the clay just mentioned. Orton called the writer's attention to several exposures in the city of Columbus where bowlders abound at a depth of 4 or 5 feet beneath the silty clay. This peculiar distribution of bowlders has not been observed outside the city of Columbus, either by Professor Orton or the writer, but may be widely developed in the silt-covered portion of the basin, no special search for the bowlders having been made.

The gravel belts along streams are most conspicuous on the Scioto and Olentangy rivers, Darby Creek, and the lower course of Big Walnut (from the latitude of Columbus southward). The gravel along the Scioto is in places capped by a few feet of till which seems to indicate that its deposition occurred before the final retreat of the ice from this region and opposes the view that it was an outwash from the Powell moraine. The belt on the Scioto is narrow above Columbus, but is well defined all along the brow of the bluffs of the rock gorge extending back 100 to 200 yards on either side of the rock bluffs. Below Columbus the rock bluffs disappear and the gravel belt has a width of a mile or more. Its eastern border is followed nearly by the canal all the way from Columbus to Circleville. The west border lies back from the river at varying distances from a few yards up to nearly a mile and, in the vicinity of Circleville, is, as noted above, 2 or 3 miles from the river. On Olentangy River the gravelly belt is one-half mile or more in breadth. Possibly it marks the line of discharge for the main glacial stream leading down from the Powell moraine north of Columbus, though it seems quite as probable that its deposition preceded the formation of that moraine.

On Darby Creek the gravel in the lower part is confined to the valley of the stream, but in the upper part above Plain City considerable gravel is found in the plains bordering the valley. This gravel is perhaps an outwash from the Powell moraine, which lies north of that part of the creek. South from Plain City the bluffs wherever examined contain till. In the valley in Pickaway County, are terraces which may be of glacial age,

standing 20 or 30 feet above the stream, and occupying in places nearly the whole width of the valley. These terraces may perhaps have suffered some reduction from their original level. If not they indicate that less excavation has taken place since they were formed than took place between the withdrawal of the ice from the border plain and the deposition of the gravel.

On Big Walnut Creek till is present above the latitude of Columbus, but from that latitude southward there seems to be but little within a mile or more east from the creek, the drift being gravelly. For a few miles above the mouth of Black Lick, an eastern tributary, the interval between the two creeks, 1 to 2 miles in width, is occupied by a gravel plain which stands 20 to 30 feet above Big Walnut Creek. The belt is narrower below the mouth of Black Lick, but continues to the Scioto. Bowlders were observed on the surface of the broad portion of this plain, about 2 miles above the mouth of Black Lick, which are either at the surface or embedded a foot or two in a brown clay that caps the gravel. This clay is seldom more than 3 or 4 feet thick, and usually but 12 to 18 inches.

In Madison County there are belts of land slightly depressed below bordering till plains that are said to be underlain by gravel. They are known as "glade," and the timber on them differs from that on the bordering till tracts, being nearly all white oak without underbrush, while the bordering tracts have a variety of timber and much underbrush. The gravel of these glades is probably of glacial age, but the mode of deposition and points of connection with the ice margin have not been worked out.

The following represent the principal well sections obtained in which the drift has notable thickness.

At Westerville the gas well passed through 94 feet of drift.

The boring for gas at Plain City penetrated 119 feet of drift. This boring has about 10 feet of gravel and sand at surface, the remainder of the drift being mainly blue till. The well mouth stands 15 feet below the level of the railway station, or 919 feet above tide.

At Columbus the statehouse well, sunk in 1857–1860, penetrates 123 feet of clay, sand, and gravel.[1] The gas well made on the banks of the Olentangy River in 1886 penetrated 104 feet of drift.[2] The altitude of the well mouth is 737 feet above tide. At J. M. Linton's, near the Scioto, 2

[1] Geology of Ohio, Vol. I, 1873, p. 113.

[2] Ibid., Vol. VI, 1888, pp. 281–282.

miles south of the statehouse, an artesian well passed through 106 feet of drift, of which the upper 50 feet is gravel and the remainder sand. Water comes from below shale at a depth of 148 feet. The water rises 3 or 4 feet above the level of the canal at Columbus.

At the starch factory in the south part of Columbus, near the canal and river, several flowing wells have been obtained from the drift at depths ranging from 40 to 90 feet. They are said to pass through "hardpan" just above the water vein. Whether this hardpan is till or cemented gravel was not learned. The main part of the drift penetrated was gravel.

At the Lutheran College, in the east part of Columbus near Alum Creek, a well 110 feet deep did not reach hard rock, but may have entered shale. At the waterworks on Alum Creek several flowing wells were obtained at depths of 30 to 40 feet. They penetrated about 12 feet of gravel at the surface and were then in till to the water vein. This water is strongly chalybeate. The bluffs on Alum Creek on each side of the waterworks are composed of till; the gravel is therefore strictly a valley deposit. Orton has made the following statements concerning the erosion near Columbus:[1]

> The erosion has been especially extensive near the junction of the two rivers. For 3 miles at least above the mouth of the Olentangy the rocks between the rivers have been cut away to such a depth that no trace of them is now visible even in the deepest wells that are dug. The drift deposits that take their place do not rise to the same altitude that the surrounding uplands attain, and thus the whole of the country, from North Columbus westward to the Scioto, belongs in the category of lowlands.

Immediately north of this lowland tract the altitude is not only greater, but the drift much thinner, so that the erosion was far greater than is indicated by variations in the level of the present surface.

On the plain southwest from Columbus the drift is 10 to 50 feet or more in thickness. On Darby Creek there are occasional outcrops of rock in Franklin County as far south as Harrisonville, but from that village to its mouth no outcrops were observed, though the valley is in places 75 feet in depth. In the portion of Deer Creek immediately west from the lower portion of Darby Creek, rock outcrops are numerous. The heavy drift does not, therefore, extend much farther west than Darby Creek. It may occupy the entire interval between that creek and the Scioto in Pickaway County.

[1] Geology of Ohio, Vol. III, 1878, p. 599.

Near the southwestern border of this plain, in Madison County, the drift probably exceeds 100 feet in average depth. The borings for gas at London are the only ones reported that have reached rock. These, as previously noted, have in one case 155 feet of drift, and in another 200 feet. East from the Scioto numerous exposures of rock occur along the main creeks, and some hills, near Lithopolis, rising much above the level of the plain, have rock at surface. This does not, however, prove the absence of valleys with heavy drift deposits; indeed, such valleys probably traverse this district. Orton called attention, as follows, to .evidence that in preglacial times the Olentangy Valley was a prominent channel traversing the Scioto Basin:[1]

The levels run in the construction of the Worthington and Dublin turnpike show that low water in the Olentangy west of Worthington is 16 feet lower than low water in the Scioto at Dublin. The Scioto exceeds the Olentangy several times in volume, and, other things being equal, its valley should be much deeper. It is also to be noted that the disparity would be still more striking if the actual depths of the valleys were taken into the account. The Olentangy runs upon drift beds, the shales having been cut out to an unknown but probably considerable depth, while the Scioto at the point named has a rocky floor. The contrast between the valleys in width is equally marked. As already stated, the Scioto Valley in the northern half of the county is but a narrow gorge, walled with vertical cliffs. Its bottom lands are of small extent and often there is no interval whatever. The valley of the Olentangy, on the other hand, often attains a width of 2 miles, and is seldom less than half a mile.

BOWLDER BELTS.

The impression prevails among the residents on the plains southwest of Columbus that there are bowlder belts some miles in length that traverse the district at angles quite different from the trend of the bordering moraines. One of these is said to pass from the uplands $1\frac{1}{2}$ miles southwest of Darbyville, eastward across Darby Creek and the uplands between that stream and the Scioto, coming to the Scioto nearly opposite the mouth of Little Walnut Creek. The writer has crossed this supposed bowlder belt at several points and endeavored to outline its course and width, but found that it is not sufficiently well defined to admit of ready mapping. In a general way, however, it may be said that bowlders are more numerous along the line designated than on the bordering tracts, though intervals of one-half mile or more occur along the line where bowlders are rare, while

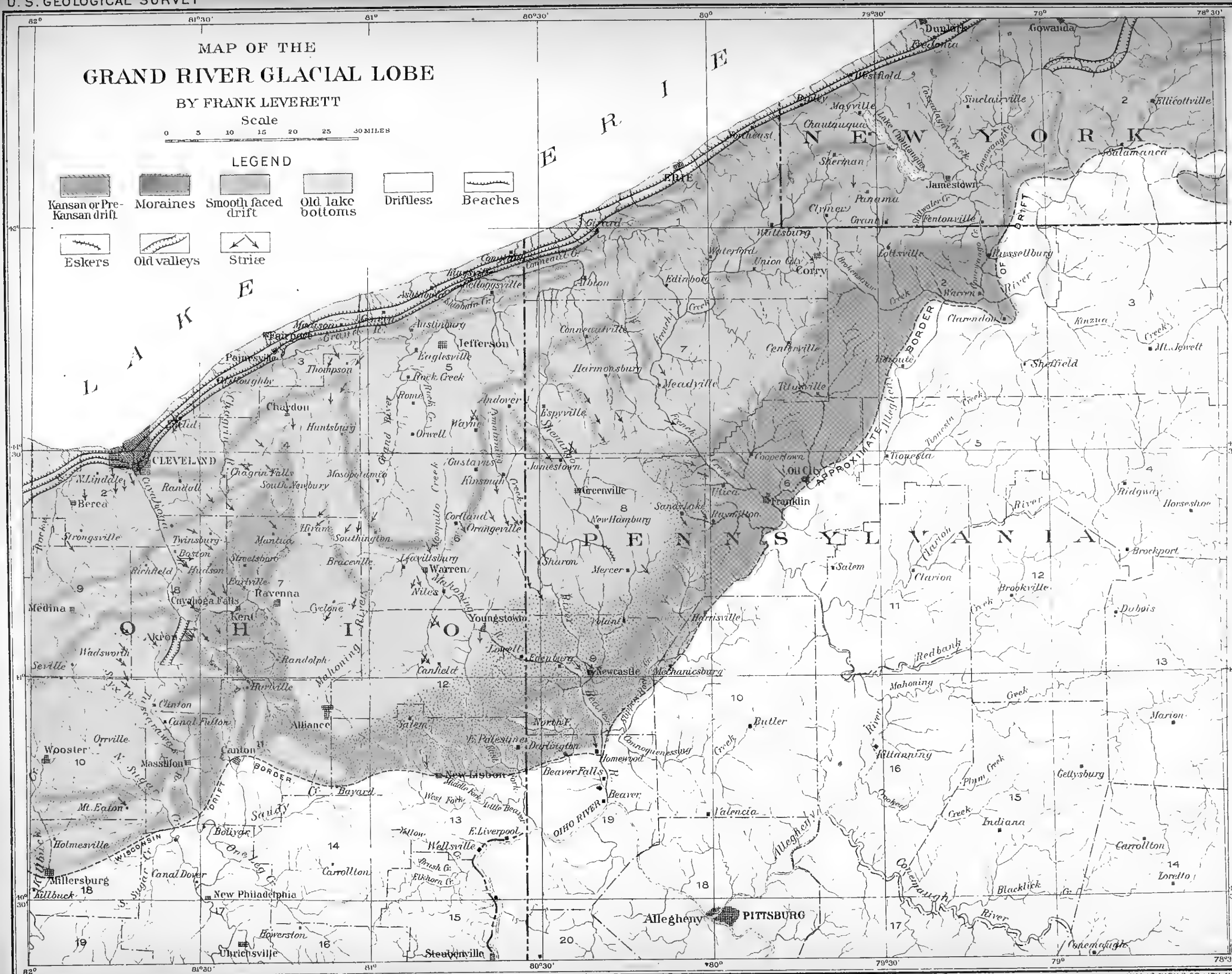
[1] Geology of Ohio, Vol. III, pp. 598, 599.

in places on bordering tracts they are numerous, so that there does not appear to be a well-defined belt. Probably the bowlders were deposited during the retreat of the ice from west to east, surface bowlders having accumulated on the ice sheet along a line in harmony with the direction of movement.

Another tract where bowlders are sufficiently numerous to excite remark lies between Midway and Mount Sterling. The writer did not examine this district so carefully as the other, but has the impression that it will be even more difficult here to make out a belt or train of bowlders than in the district just described. Aside from these two districts no extensive tracts were reported where bowlders are conspicuous; they are, however, not rare in any part of this inner border plain except where silt deposits occur, as noted above.

INNER BORDER PHENOMENA IN THE SHOULDER.

In the shoulder east of the main Scioto lobe, there is, between the main morainic system and a series of moraines which follow the continental divide, a hilly district covering southwestern Summit, southeastern Medina, northern Wayne, and central Ashland counties, in which occasional small tracts were noted that have morainic topography, but the greater part of which is nearly free from drift knolls and covered with but a thin drift deposit. It is thought that these small morainic tracts are the correlatives of the feeble though well-defined moraines which appear in the northern part of the Scioto Basin, and which are described below under the name of Powell and Broadway moraines, since they lie, as those moraines do, between the main morainic system and that series. These moraines are easily traceable in the smooth Scioto Basin, but in this hilly district would be recognized only by very careful tracing. The ice sheet appears to have formed less continuous ridged or morainic deposits in this district than in the Scioto Basin, for, after careful examination, the writer has been unable to connect into a belt the several patches of morainic topography which were observed. The drift has an average thickness of scarcely 20 feet on uplands, and is composed mainly of till. It is thinner and more compact than the drift in the moraines to the south. The valley drift has greater thickness. That found in tributaries of the Tuscarawas and of Killbuck and Mohican creeks, which head in the moraines north of this district, is considered in connection with those moraines.



LIST OF COUNTIES

OHIO

1 LORAIN
2 CUYAHOGA
3 LAKE
4 GEAUGA
5 ASHTABULA
6 TRUMBULL
7 PORTAGE
8 SUMMIT
9 MEDINA
10 WAYNE
11 STARK
12 MAHONING
13 COLUMBIANA
14 CARROLL
15 JEFFERSON
16 HARRISON
17 TUSCARAWAS
18 HOLMES
19 COSHOCTON

PENNSYLVANIA

1 ERIE
2 WARREN
3 McKEAN
4 ELK
5 FOREST
6 VENANGO
7 CRAWFORD
8 MERCER
9 LAWRENCE
10 BUTLER
11 CLARION
12 JEFFERSON
13 CLEARFIELD
14 CAMBRIA
15 INDIANA
16 ARMSTRONG
17 WESTMORELAND
18 ALLEGHENY
19 BEAVER
20 WASHINGTON

NEW YORK

1 CHAUTAUQUA
2 CATTARAUGUS

SECTION III. IN THE GRAND RIVER LOBE.

MORAINES OF THE SYSTEM.

The morainic system discussed under the above title constitutes a part of the great system described by Chamberlin as the terminal moraine of the second Glacial epoch,[1] and is a continuation of the system described in Sections I and II. The term morainic system is applied because of the complexity of the belt, for it includes several moraines whose formation was probably continued through a series of oscillations of the ice front. Chamberlin called attention[2] to its massiveness and complexity, showing that it usually covers a breadth of several miles, and contains a confusedly arranged series of morainic ridges which are only in part separable into distinct belts. The portion comprising the outer morainic system of the Grand River lobe is, on the whole, less clearly separable into distinct belts than the correlative system in lobes farther to the west.

DISTRIBUTION.

By reference to Pls. II and XV the course and breadth of the moraine, and also the size and form of the ice lobe, may be learned. There is a well-defined morainic belt encircling the Grand River Basin, and leading northeastward into New York a few miles beyond the point of the reentrant angle in the glacial boundary near Salamanca, N. Y. The moraine dies out on elevated uplands near the village of Cattaraugus, and some uncertainty is felt concerning its continuation. Whether it finds its continuation along the line of the terminal moraine traced by Lewis[3] from the reentrant angle southeastward across northern Pennsylvania, or takes an eastward course farther north, embracing part of the moraines discussed by Chamberlin in the Third Annual Report,[4] remains to be determined. Should the latter prove to be the line of continuation, the moraine traced by Lewis may fall within the early Wisconsin series.

The distribution of the moraine may be briefly outlined as follows: From the reentrant angle near Salamanca southwestward the morainic system is found to run nearly parallel with the Allegheny Valley, but is

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[1] Third Ann. Rept. U. S. Geol. Survey, pp. 291–402.
[2] Ibid., pp. 307, 310, et seq.
[3] Second Geol. Survey Pennsylvania, Rept. Z, by H. C. Lewis.
[4] Third Ann. Rept. U. S. Geol. Survey, pp. 347–350, Pl. XXXIII.

separated from it by a space of several miles, as far down as the bend of the stream near Franklin, Pa. In southwestern New York and in Warren County, Pa., it has a breadth of but 3 or 4 miles, being narrower here than in any other part of the district examined. In western Warren County it curves to the southwest, and maintains this course through southeastern Crawford County. Its breadth increases in the latter county to about 7 miles at the south line. Near the corner of Crawford, Mercer, and Venango counties it swings southward, and at its curve has a breadth of 15 miles, the greatest breadth exhibited anywhere inthe eastern limb.

From this point it departs more widely from the Allegheny. The outer border touches the villages of Harrisville, Centerville, and West Liberty in Butler County, and at the latter village swings abruptly westward, entering Lawrence County near Rose Point. The inner border in this portion is not so easily mapped as the outer, being much less regular and presenting a less marked contrast to adjacent districts.

Around the southern end of the lobe (in Lawrence and Beaver counties, Pa., and Columbiana and Mahoning counties, Ohio) the morainic system spreads out to a breadth of 15 miles or more. The southernmost point reached by it is in the vicinity of Bayard, in southwestern Columbiana County, Ohio. In eastern Stark County the belt is double, there being a feeble outer member which passes from Bayard north of west near Osnaburg to Canton, while the main moraine passes northwest through Freeburg, Strasburg, Barryville, and Marlboro to Hartsville, near which it meets the main moraine belonging to the shoulder or shelf of the Scioto lobe. The outer member connects at Canton with the outer moraine of this shoulder.

From Canton northward, nearly to Chardon, a distance of about 50 miles, there is a massive interlobate belt which, from Canton to the latitude of Kent, maintains a breadth of 12 to 15 miles, but becomes narrower north from there, terminating a few miles south of Chardon, with a width of scarcely a mile. It is probable that the greater part, if not all, of the interlobate belt that lies north of Kent and west of the Cuyahoga River was formed from the west, since all the striæ yet discovered on that side of the river have a bearing east of south; but the portion on the east side from Kent northward, as indicated by striæ bearing west of south, apparently belongs to the Grand River lobe. South from Kent the line of junction of

the two lobes, as already indicated, is less clearly shown, since no striæ have been discovered within the moraine, and there is no continuous gravel plain traversing its midst from north to south.

Gravel terraces lead from the interlobate moraine southward along the several streams which have their source in it, viz, the Tuscarawas River and the branches of Nimishillen Creek, the head of the terrace being near Canal Fulton on the Tuscarawas River, and near Middlebranch and New Berlin on the middle and west branches of Nimishillen Creek. Farther north the moraine incloses several lakes which are sometimes connected into a chain by a series of marshes and gravel plains, but have either narrow outlets or are without outlets to the southward-flowing streams. Hence their significance is not clear. It seems probable that a shifting of the margin of the ice sheet or of the line of coalescence between the lobes had blocked up drainage lines that led southward, and left portions of the channels unfilled. It is not improbable that by more detailed and critical study of the features and the structure of the interlobate tract, there will be found sufficiently clear evidence to justify a decision as to overriding or shifting of the ice margin.

RANGE IN ALTITUDE.

The course of this moraine being over prominent ridges and deep valleys on the western slope of the Alleghenies, there is a great range in altitude.

The following table of altitudes along the portion of the moraine in Ohio and Pennsylvania is based largely upon barometric readings, but few accurate levels being available.

Altitudes along outer moraine.

Location.	Altitude above tide.	Authority.
	Feet.	
Highlands east of Conewango River	2,050	Carll.
Conewango Valley, at Russellburg	1,233	Dunkirk, Allegheny Valley and Pittsburg R. R.
Highlands west of Russellburg	1,950	Barometric.
Chandlers Valley	1,450	Barometric.
Highlands east of Wrightsville	1,900–1,980	Pike Rock, 1,980 feet, barometric.
Wrightsville	1,350	Barometric.
Highlands west of Wrightsville	1,900	Barometric

Altitudes along outer moraine—Continued.

Location.	Altitude above tide.	Authority.
	Feet.	
Blue Eye Creek, at source	1, 600	Barometric.
Highlands between Blue Eye and Big Brokenstraw creeks.	1, 700–1, 850	Barometric.
Spring Creek station	1, 395	Pennsylvania Railroad.
Near State road, line of Crawford and Warren counties.	1, 830–1, 880	Turnpike survey.
Eastman	1, 740	Turnpike survey.
Oil Creek Valley, at Centerville	1, 238	Western New York and Pennsylvania R. R.
Oil Creek Valley, at Hydetown	1, 239	Western New York and Pennsylvania R. R.
Highlands west of Hydetown	1,600–1, 650	Barometric.
Sugar Creek Valley, near Crawford and Venango County line.	1, 340	Barometric.
Moraine at East Randolph church	1, 580	Barometric.
French Creek Valley, at Cochranton	1, 065	Erie Railroad.
French Creek Valley, at Utica	1, 035	Erie Railroad.
Moraine at county line, west of Utica	1, 425	Barometric.
Sandy Creek Valley, at Raymilton	1, 138	Lake Shore and Michigan Southern R. R.
Sandy Creek Valley, at Sandy Lake	1, 165	Lake Shore and Michigan Southern R. R.
Moraine at Mr. Barnes's, west of Harrisville.	1, 400	Barometric.
Beaver River Valley, Lawrence Junction	774	Pittsburg, Fort Wayne and Chicago R. R.
Moraine in Beaver Valley	830–900	Barometric.
Highlands east of Galilee	1, 150–1, 200	Barometric.
Little Beaver Valley, north of Galilee	1, 000	Barometric.
High point on State line east of Palestine	1, 250	Barometric.
State line, lowlands	1, 000±	Barometric.
Palestine, Ohio	1, 015	Pittsburg, Fort Wayne and Chicago R. R.
New Waterford	1, 063	Pittsburg, Fort Wayne and Chicago R. R.
Columbiana	1, 113	Pittsburg, Fort Wayne and Chicago R. R.
Leetonia	1, 016	Pittsburg, Fort Wayne and Chicago R. R.
Salem	1, 193–1, 334	Geology of Ohio, Vol. VI.
Damascus	1, 188–1, 260	Estimate from railroad.
North Georgetown	1, 170	Barometric.
East Rochester	1, 082	Cleveland and Pittsburg Railroad.
Bayard	1, 076	Cleveland and Pittsburg Railroad.
Homeworth	1, 150	Cleveland and Pittsburg Railroad.
Summit north of Homeworth	1, 200	Cleveland and Pittsburg Railroad.
Uplands east of Homeworth	1, 290	Barometric.
Uplands west of Homeworth	1, 300	Barometric.
Alliance	1, 100–1, 160	Estimate from railroad.
Strasburg	1, 187	Pittsburg, Fort Wayne and Chicago R. R.
Louisville	1, 187	Pittsburg, Fort Wayne and Chicago R. R.

Altitudes along outer moraine—Continued.

Location.	Altitude above tide.	Authority.
	Feet.	
Canton, at Pittsburg, Fort Wayne and Chicago station.	1,047	Pittsburg, Fort Wayne and Chicago R. R.
Canton, at Valley Railroad station	1,029	Valley Railroad.
On elevated part of city	1,100–1,150	Barometric.
Uplands 3 miles northeast of Middlebranch.	1,180	Barometric.
Middlebranch	1,123	Cleveland and Canton Railroad.
Hartsville	1,170	Cleveland and Canton Railroad.
Summit north of Hartsville	1,179	Cleveland and Canton Railroad.
Suffield	1,143	Cleveland and Canton Railroad.
Mogadore	1,108	Cleveland and Canton Railroad.
Summit north of Mogadore	1,151	Cleveland and Canton Railroad.
Edinburg	1,183	Ohio geological survey.
Kent	1,053	Erie Railroad.
Summit, near Freedom	1,186	Erie Railroad.
Ravenna	1,070–1,133	Estimate from railroad.
Charlestown Center	1,148	Ohio geological survey.
Mantua	1,109–1,200	Estimate from railroad.
Highlands west of Hiram	1,336	Colton's survey.
Claridon geodetic station	1,336	East of moraine, U. S. Lake Survey.
Chester geodetic station	1,292	West of moraine, U. S. Lake Survey.

TOPOGRAPHY.

In Warren and Crawford counties, Pa., where the morainic system is narrowest, there is a hummocky topography in its entire width of 3 to 7 miles. On the highlands the knolls are lower than in the valleys, but in both situations they are sharp and inclose basins whose slopes are so abrupt that they are often difficult to cultivate. The knolls in the valleys range from 15 to 100 feet in height, while those on the uplands are but 10 to 25 feet. The individual knolls have areas ranging from a fraction of an acre up to 10 acres or more. The valley slopes are dotted with drift knolls whose contours are fresh and altered scarcely more by erosion than are those of the upland knolls. The heavy forests which cover this region have served to check erosion to a great degree, as may be seen by a comparison of fields which have been cleared and cultivated for a half century with those on which the forest still stands. Cultivation of the soil, together with free

access and escape of water, have produced so marked an effect within a few years as to render it probable that the forests or some other protective vegetation took possession soon after the ice sheet withdrew, and thus preserved the sharp contours of the moraine.

In Mercer and Lawrence counties, Pa., and in eastern Ohio, where the morainic system is much broader than it is in Crawford and Warren counties, Pa., much variation is displayed. The outer portion for a width of 5 miles, more or less, presents a knob-and-basin topography similar to that in Warren and Crawford counties, while the inner portion has a gentle swell-and-sag topography, with an occasional tract of a square mile or more where morainic features are sharper. In this inner portion the higher swells are 20 feet or more in height, but the majority fall below 15 feet. Knolls only 10 to 15 feet in height often cover an area of several acres. In some localities swells are rare, much of the surface being nearly plane, but as a rule they are sufficiently numerous to give the moraine a topography strikingly in contrast with the plane tracts on its inner border. The outer (knob-and-basin) portion in eastern Ohio and Mercer and Lawrence counties, Pa., may be the equivalent of the entire morainic system in Warren and Crawford counties. In that case the inner (swell-and-sag) portion is so poorly developed in the latter counties as to have escaped recognition. In lobes to the west a full equivalent is probably found in moraines with swell-and-sag topography, which lie north of the main morainic system.

In the interlobate tract west of the Mahoning and Grand rivers the topography is bolder, with sharp conical knolls or winding ridges and hills of drift, 30 to 50 feet or more in height, and among these are numerous marshes and lakelets. The greater part of the surface is strongly morainic, but, as noted above, some small gravel plains occur among the knolls, usually bordering the marshes and lakelets. Concerning this interlobate moraine, and contrasting it with portions of the kettle moraine farther west, Chamberlin remarks as follows:[1]

> It is quite characteristically developed, though it has a predominant gravelly constitution, and takes on the kamelike phase of accumulation. It is, however, inferior in strength, roughness, and coarseness to portions of the range elsewhere. This is the most pronounced development of the range in Ohio, and is the only portion, I think, to which attention had been called previous to the recent geological survey of that State.

[1] Third Ann. Rept. U. S. Geol. Survey, p. 339.

In the discussion of topography just given the remarks have been of a general nature in order that the salient features might be clearly set forth. In that which follows the topography is described in more detail.

In locating the ice margin in the valleys the writer has used the commonly accepted criteria of hummocky topography, accompanied often by bowlders, placing the margin at the point where a change to level-surfaced deposits set in. This has led to a different interpretation from that given by Lewis and Wright in the report on the terminal moraine in Pennsylvania,[1] for their criteria were evidently somewhat different. They include in the moraine only the till deposits and bowlder belts, and exclude the large knolls and ridges containing stratified drift so commonly found at the head of terraces, classing them as the product of water action in a recess or embayment in the ice. That water played a prominent part in the formation of these knolls of stratified drift at the head of glacial terraces can not be doubted, but it is equally certain that these knolls constitute integral parts of the moraine, since their form is such as would have been produced only by the aid of the mechanical action of the ice sheet. The presence of surface bowlders also shows that the ice occupied the valleys till the knolls and ridges had acquired essentially their present form. The morainic topography and the surface bowlders seem to the writer more essential characteristics of a terminal moraine than the till. Furthermore, the stratified material and the till in these valleys, as well as in the upland portions of the moraine, grade into each other, or alternate in such a manner that their border line is very indefinite, and in places the topography affords the only reliable basis of interpretation. For example, in one valley, that of Oil Creek, no till or bowlder belt was discovered, and as a consequence Lewis and Wright were obliged to carry the ice margin across, where, according to their criteria, there was no evidence of its presence. In this valley they placed the margin about 2 miles above the head of the terrace, excluding, because of its gravelly constitution, the best developed morainic topography in the valley.

The valleys which illustrate this difference of mapping of the morainic border are those of the Conewango River, Jacksons Run, Big Brokenstraw and Oil creeks, and Beaver River, in each of which the writer has extended the morainic border southward from 1 to 3 miles beyond the limit set by

[1] Second Geol. Survey Pennsylvania, Rept. Z.

Lewis and Wright. Near Mechanicsburg, in Butler County, there are semistratified hillocks and ridges considered by them extramorainic, which the writer has included in the moraine. In French Creek Valley the writer's mapping of the morainic border agrees with theirs.

In the Conewango Valley, at Ackley, the moraine presents a sharply defined border, rising 50 to 75 feet above a plain which for several miles north occupies the valley. For 3 or 4 miles below Ackley the valley is so filled by morainic deposits that the stream is restricted in places to a passage scarcely twice as wide as its bed, and is bordered by knolls rising 30 to 100 feet above it. The knolls are in groups, loosely connected and inclosing kettle holes. As a whole, they present a very billowy appearance. Near the south line of Pine Township, a mile or more below Russellburg, the knolls are reduced to low swells and finally die away in a level terrace. This terrace at its head stands about 30 feet above the river and occupies the valley from there to its mouth, descending somewhat faster than its present flood plain. Bowlders are especially numerous near Ackley, and are not rare on any part of the moraine between Ackley and the head of the terrace. On the terrace none were observed. As determined by Lewis and Wright, the moraine is finely developed on the slopes each side of the Conewango and on the very elevated uplands.[1]

On the next valley west of the Conewango, that of Jacksons Run, the moraine formed a complete obstruction to the passage of the stream and constitutes a divide between streams flowing to the north and to the south. Its best development is in the vicinity of the village of Chandlers Valley, where kettleholes, sharp conical hills, and winding ridges of sandy till abound. The ridges are about 20 to 40 feet in height. A mile below this village is the head of the terrace formed by the glacial waters. Between the head of this terrace and Chandlers Valley a portion of the drift deposits are nearly level topped and have the appearance of a higher terrace, being banked against the bluff. But out in the midst of the valley there are knolls at lower levels than the high bench, and the terrace that leads down the valley heads among these knolls. The significance of the higher bench was not determined.

On the uplands between Chandlers Valley and Little Brokenstraw Creek the moraine is as finely developed on the elevated points as on the lower

[1] Second Geol. Survey Pennsylvania, Rept. Z, p. 169.

parts of the uplands, consisting of sharp hillocks and ridges 10 to 25 feet in height, among which shallow basins are inclosed.

In Little Brokenstraw Valley the inner (north) border of the moraine is about as sharply defined as on the Conewango. The valley, which is comparatively open for some miles above the moraine, is so filled where the moraine crosses that the stream in making its passage through winds about among the drift ridges. The height of the most prominent knolls and ridges is about 40 feet, but the majority have a height of only 20 to 25 feet. This valley was not examined below the moraine, hence no data can be furnished concerning its terraces.

The best display of morainic topography along Big Brokenstraw Creek is found south of Spring Creek station. For a mile or so south and southwest of this station the valley bottom presents a very diversified surface, there being hummocks and basins, ridges and sloughs, with sharp oscillations of 10 to 25 feet. The ice here, as in Jacksons Run, probably overhung, if it did not rest upon, the drift knolls, and determined the peculiar form which they exhibit.

Not only is there morainic topography in Oil Creek Valley for 2 miles below Lewis and Wright's boundary line, but there is abundance of till on the slopes and uplands outside their boundary, immediately north of Hydetown, and sharp drift knolls along McLaughlin Creek. The boundary should, therefore, be located along a nearly direct line across the valley from the uplands northeast to those west of Hydetown. The head of the terrace at Hydetown is 60 to 75 feet above the creek and slightly undulatory. The moraine rises only to a slight altitude above the head of the terrace. It does not fill the valley so completely as it does the valleys in Warren County, just mentioned.

An interesting change in the rate of fall of the present stream in this valley, near the outer border of the moraine, was noted by White.[1] In a distance of nearly 10 miles by course of stream from Centerville to Hydetown the fall is but 45 feet, while from Hydetown to Titusville, a distance of $3\frac{3}{4}$ miles, the fall is 70 feet. This change of fall in the stream coincides quite closely with the outer border of the moraine, the rapid fall being outside the moraine where the glacial waters formed an abruptly descending terrace, and the slow fall in the midst of the moraine where the channel has been opened since the ice sheet withdrew.

[1] Second Geol. Survey Pennsylvania, Rept. Q^4, pp. 28–29.

In the valley of the East Branch of Sugar Creek, a mile or more south of Townville, the moraine is better developed than farther south, the valley being open—i. e., more free from knolls—as the outer border of the moraine is approached. No well-defined moraine-headed terrace was observed, but leading down the valley is a broad plain slightly above the level of the stream. This plain is the result of a gravel filling of 100 feet or more in the old valley, and probably bears the same relation to the moraines as do the more elevated moraine-headed terraces of other valleys.

On the west or Lake Branch of Sugar Creek the moraine is finely developed from Sugar Lake down to the Venango County line, where terraces set in. It carries numerous sharp conical knolls and sharp ridges, among which basins are inclosed. Below Coopertown the moraine returns to Sugar Creek Valley, where it is finely developed, though its knolls are less sharp and numerous than on the uplands west of the creek.

In French Creek Valley, from its mouth up to the Venango County Infirmary, a distance of 5 miles, the moraine-headed terrace appears as a smooth plain, standing about 50 feet above the level of the creek. Just west of the infirmary an abrupt rise of 15 to 20 feet is made, and it has above this point an undulating surface. Between the infirmary and Utica there are places where the moraine resembles somewhat a pitted plain, its surface having a nearly uniform altitude, 60 to 70 feet above the creek, and being in some cases broad and level topped. Basins occur on it that are depressed 10 to 20 feet below the general level of the glacial filling. In places, however, it presents a hummocky topography. In explanation of this peculiar topography it is suggested that the ice sheet may have encroached upon an old terrace and only slightly modified the surface. Above Utica the drift aggregations in the valley assume the ordinary morainic type, there being numerous sharp knolls and winding ridges of unequal height (15 to 60 feet), among which small basins 15 to 25 feet in depth occur.

The rate of fall of the stream increases near the outer border of the moraine, but not in so marked a degree as on Oil Creek. According to levels reported by White[1] the fall from Meadville to the line of Crawford and Mercer counties is but 20 feet in a distance of $12\frac{1}{4}$ miles, while from the Crawford County line to its mouth, a distance of 15 miles, there is a

[1] Second Geol. Survey Pennsylvania, Rept. Q^4, p. 26.

fall of 75 feet. As in Oil Creek Valley, this change in rate of fall is probably due to the relationship to the ice margin, the rapid fall being outside of, and in the outer part of, the moraine, while the lesser rate occurs above the moraine and in its inner portion.

On Big Sandy Creek no examinations were made below Raymilton; but just west of that village a gravel terrace standing about 50 feet above the creek has its head in a series of drift knolls whose summits scarcely rise above the terrace. For several miles above this point knolls and ridges abound, but their height seldom exceeds 20 feet.

In Little Shenango Valley strongly morainic topography is entered near Clarks Station, the valley being nearly filled with knolls and ridges for a distance of 3 or 4 miles. Their height ranges from 10 to 40 feet or more, and their slopes are very abrupt. On the uplands between Big Sandy and Slippery Rock creeks the general description previously given will apply, there being in the outer portion of the morainic system a knob-and-basin and in the inner a swell-and-sag tract.

On the southeast side of Slippery Rock Creek, in northwestern Butler County, is a tract of sharply ridged drift, which Lewis and Wright considered extramoraïnic, as they did the hummocky drift of some of the valleys of Warren and Crawford counties. The following description is taken from Lewis's report:[1]

> In front of the moraine at this point and extending for a mile or more southeastward is a magnificent kame-like accumulation of sandy stratified drift. A remarkable series of hummocks and interlacing hills inclosing basin-like depressions rises above the surface of the surrounding country at least 100 feet in height. The sides of the sandy ridges are very steep and the whole kame, if such it be, is as fine as any along the whole line of the moraine. * * * This kame-like accumulation is of special interest, in that it lies in front of the moraine and that it is not in the immediate valley of a modern creek. South of the kame another one of almost equal interest starts from a portion of the moraine a mile farther west and forms a steep and straight ridge 2 miles long. It runs along a valley and in part along a small stream in a direction south of east, and can be traced continuously from Mechanicsburg to within one-half mile of West Liberty in Brady Township. * * * It lies at the foot of the moraine and is a steep ridge of sandy stratified gravel, in which are no large bowlders, and all the pebbles of which are waterworn. The ridge is narrow and straight at first, but in Brady Township it seems to consist of several reticulated ridges. It evidently represents an ancient water course and is worthy of more extended study.

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[1] Second Geol. Survey Pennsylvania, Rept. Z, p. 185.

According to the usual methods of interpretation the last-described ridge is an esker. At its southeast end, near Boyd's residence, in western Brady Township, it terminates in a gravel plain. Along the north side of the esker are marshes and gravelly knolls and ridges associated in morainic fashion; south of it are highland tracts on which there is scarcely any drift. The height of this ridge and of the associated knolls and ridges on its north side is scarcely 20 feet, with the exception of one knoll just north of Mr. Boyd's residence, which is about 50 feet high. The large ridge northeast of this esker, mentioned first in Lewis's description, may have a rock nucleus, there being on its north slope slight outcrops of sandstone which appear to be in situ; one of them has a continuous horizontal exposure of fully 20 feet. There are associated with this several loose blocks of sandstone. The esker and accompanying knolls and ridges occupy a lowland tract south of Slippery Rock Creek, into which the ice sheet projected slightly beyond the regular border line, the boundary being nearly a north-to-south line on its east side and an east-to-west line on its south side. These features are such as Lewis and Wright have considered morainic in adjacent districts on the west and north, and it is not apparent why they should consider them extramorainic here. The presence of short ridges of an esker type is quite characteristic of the moraine for several miles to the north from this so-called extramorainic belt, and there is much more assorted material than till in the knolls and ridges. This gravelly portion was included by Lewis and Wright in the moraine. They also included a gravelly portion of the moraine to the west near Rose Point, in which there is little, if any, till, the basins and lower lands, as well as the knolls and ridges, being underlain by gravel.

In the northern part of Newcastle, on uplands standing 120 feet more or less above the Shenango Valley, there is a winding gravel ridge, probably allied to the eskers. It is about one-half mile long, 12 to 15 feet high, and 6 to 8 rods wide. Taken as a whole, its trend is N. 60° W. to S. 60° E., or nearly in line with the striation in that vicinity, which is S. 45° E., but in its windings it has variations from a north-south to a nearly east-west course. Its structure is peculiar, there being a capping of till 3 to 5 feet thick above a nucleus of assorted material. It is very seldom that eskers carry a till capping, gravel usually being found on the surface as well as below, but the ridge apparently belongs to this class of formations. The till which caps it was perhaps englacial material.

In the valleys of Shenango and Beaver rivers below Newcastle there is a peculiar combination of moraine and terrace. Near the mouth of the Shenango there are terrace-like benches, about 100 feet high, that are capped by till, and back of these benches on the slope of the bluff morainic features appear. A few miles below, in the vicinity of the glacial boundary, these terrace-like benches break up into a series of reticulated, nearly level-topped ridges, among which basins and low marshy tracts are inclosed. Nearly the entire breadth of the valley is occupied by these ridges and basins, whereas a few miles above a broad, low tract borders the river, leaving the bench and drift knolls referred to as a narrow fringe along the bluffs.

Below Chewton, Beaver River enters a narrow valley or gorge. Bordering the gorge, at a level 130 to 150 feet above the river, there is a gradation plain nearly a mile in width, which is concealed above this village by the morainic accumulations. This gradation plain with its capping of drift has been considered in the discussion of the deposits of drift older than the main Wisconsin moraine.

The moraine is best developed north of Chewton, but for 2 or 3 miles below this village there are occasional ridges and knolls of morainic type. Foshay and Hice have described some of these as follows:[1]

Toward the north the plain bears upon its surface a large L-shaped kame a mile in length, which reaches down to a point about one-half mile above Rock Point. This kame is composed of stratified gravel and sand and has a hummocky and irregular outline. Several kettle holes are to be seen upon its surface. The direction of the long arm of the kame is north and south, or parallel to the valley of the base-level plain here, while the short arm lies nearly at right angles to the long one and runs eastward from it, but does not reach to the bluffs at the rock gorge. The kame rises to a height of 25 to 40 feet above the base-level plain, and is from 100 to 300 yards in width. It overlies the clayey deposit of the subjacent plain, as proved by excavations into the gravel which reached the clay below, a thickness of 11 feet of the latter being here noted.

On the base-level plain of the Conoquenessing, which is half a mile wide and typically developed for about 4 miles up that stream and half a mile back from Rock Point, there is another kame about 200 yards in length and 40 feet in its greatest height. On its surface it bears a typical kettle hole, and also another partly formed. The direction of this kame is approximately north and south, or at right angles to the Conoquenessing Valley at this point. The Ellwood Short Line Railroad cuts

[1]Glacial grooves at the southern margin of the drift, by P. M. Foshay and R. R. Hice: Bull. Geol. Soc. America, Vol. II, 1891, p. 460.

through the highest part of the kame, and the exposed section shows stratified sand and gravel, with numerous bowlders up to 1 foot in diameter.

On the western side of the Beaver, just opposite the mouth of the Conoquenessing Valley, but more than half a mile back from the rock gorge, there are two smaller kame-like deposits of gravel which abut against the western-bounding hill of the base-level plain; also at Clinton, farther southward, there is another good-sized kame-like deposit. All these lie on the base-level plain.

Near the south border of these morainic knolls in the Beaver Valley, at the mouth of Clarks Run, a deposit of gravel sets in which is apparently the outwash from the ice sheet at the Wisconsin stage of glaciation. It is markedly fresher than the gravel which caps the gradation plain farther south, near the mouth of the Beaver. The altitude at the head is about 875 feet above tide, or nearly the same as the gradation plain, but it falls to 800 feet in the 10 miles to the mouth of the Beaver, and the remnants of it along the edge of the Beaver gorge appear at levels between 875 and 800 feet. This deposit at the mouth of Clarks Run has been cited by Wright as a delta accumulation of the same age as the Illinoian drift in the Ohio Valley near Cincinnati, and formed in a lake supposed to have been produced by the obstruction of the Ohio by the ice sheet.[1] But such an interpretation can not be maintained if the deposit is of Wisconsin age (as seems to be the case), for the Ohio was not occupied by the ice sheet at that time. The coarseness of the gravel deposits below the mouth of Clarks Run also favor the view that a stream of considerable vigor was discharging through the Beaver into the Ohio.

In Little Beaver Valley, near the line of Beaver and Lawrence counties, a gravel plain heads in the moraine. The latter consists of sharp knolls and ridges 20 feet or more in height. It here lies back a short distance from the glacial boundary, there being considerable till along the borders of the valley of Little Beaver River as far south as Darlington, 2 to 3 miles south of the moraine. The till in this extramorainic tract, as noted in the discussion of the early Wisconsin drift, is plentiful in the lowlands and around the base of the hills, but there is little, if any, on the highlands. It has not a hummocky surface, like the moraine. With the exception of an occasional low swell, its surface is plane.

[1] Additional evidence bearing upon the glacial history of the Upper Ohio Valley, by G. F. Wright: Am. Geologist, Vol. XI, 1893, pp. 195–199.

Continuity of the Glacial period, by G. F. Wright: Am. Jour. Sci., 3d series, Vol. XLVII, 1894, pp. 162–166.

In Columbiana and Mahoning counties, Ohio, the drift knolls are grouped irregularly, some sections having a very hummocky surface, while others have only scattering drift knolls. The outer border of the moraine was not studied sufficiently to warrant a description of the terraces connected with it. It was noted, however, that in the so-called "fringe" Wright has, in portions of Columbiana County, included moraine hillocks of as characteristic a type as those in the main moraine, from which it appears that his mapping of the "fringe" encroaches somewhat on the moraine. For example, at Bayard and east from there toward East Rochester the valley of Little Sandy Creek contains numerous sharp drift knolls and ridges, 10 to 15 feet high, among which are sharply defined basins, the contours of the moraine hillocks here being fully as sharp as anywhere in the belt. The sharpness of contour renders it improbable that these knolls are much older than the main moraine, and the topography is such as to make them a part of the moraine rather than of the outlying drift.

The moraine is well developed from Bayard northward nearly to Alliance, both in the lowland tract which the Cleveland and Pittsburg Railway utilizes and the highlands each side, and no perceptible break occurs to warrant its being distinctly separated from the main belt. A few miles to the west, however, the outer portion becomes distinctly separated by a nearly plane interval 2 or 3 miles wide. The outer belt carries low drift knolls 5 to 15 feet high, among which are shallow basins of fresh appearance. Bowlders are very numerous. The main belt from the meridian of Bayard northwestward to the interlobate moraine contains knolls and ridges 20 to 40 feet high, and shows an increasing sharpness upon approaching the interlobate tract.

The interlobate tract has for 2 or 3 miles eastward from the Cleveland and Canton Railway (which it is thought may follow nearly the border between the glacial lobes) clusters of knolls and ridges 15 to 50 feet or more in height, alternating with or surrounding basins and marshy tracts occupied by lakes or ponds. Farther east a gentle swell-and-sag topography is found. In the vicinity of Ravenna and north from there through Shalersville Township, Portage County, there are large gravelly knolls 30 to 50 feet or more in height, arranged usually in groups. There are also lakes and marshes of considerable extent, some of the larger ones having an area of 2 or 3 square miles. South of Ravenna the marshes and lakelets are

usually smaller, though some near Hartsville are equally large. North from Shalersville Township there is but little aggregation into knolls along the east side of the Cuyahoga. The ice from the Grand River lobe striated the hills of Hiram Township, and probably extended as far west as the river; but the moraine on the west side of the river was apparently formed by ice which approached from the northwest, and is accordingly discussed later in connection with the district covered by that portion of the ice sheet (pp. 545–546, 550–551).

STRUCTURE AND THICKNESS OF DRIFT.

In Pennsylvania the moraine throughout the greater part of its course consists mainly of a loose sandy till, there being a smaller amount of clay than is commonly found in the till of less rugged districts. However, there are places on the uplands, both in the midst of the moraine and in the inner border district, where a stiff clay occurs.

In Ohio the moraine contains much till, which is of a looser character than that on the plains that lie between it and Lake Erie. This difference leads to an important agricultural distinction, the loose and warm soil of the moraine being called "wheat land," while the compact and cold soil of the tract between this morainic system and Lake Erie is called clay land or "dairy land." This distinction does not prevail so strikingly now as when the country was first settled, for by an extensive system of underdraining by tile the soil of the dairy land has been opened and rendered warm. The richness of soil does not appear to differ greatly in the two districts, and there is no apparent reason why the dairy land may not in time become good wheat land.

The interlobate moraine west of the Grand River Basin contains many gravel knolls along its central portion, but the eastern and western borders carry a large preponderance of till. The till along the eastern border of the moraine, from Ravenna southward to Alliance, is very compact, and this area is called a "clay district," being similar to the clay or dairy lands of the inner border plains.

In Pennsylvania the amount of drift is not sufficient to conceal the main preglacial ridges and valleys, though, as shown in Chapter III, it has altered the drainage systems to some extent. In Ohio only the larger hills and ridges rise above a general level to which the drift filling reaches, and changes of drainage are much greater than in Pennsylvania, portions of

some of the large streams being in new channels. For example, the Cuyahoga, from Kent to the bend near Akron, is in an entirely new channel, and the preglacial course of the outlet of the upper Cuyahoga is not known, the drift sheet being so thick as to conceal quite effectually the preglacial ridges and valleys north, west, and south from Kent, and to some extent east from that city. In the main, however, eastern Ohio, like northwestern Pennsylvania, has not sufficient drift to conceal the main preglacial valleys and ridges. In both States the channels have been filled to such an extent and in such a manner as to cause the present direction of flow to be frequently the reverse of the ancient, or to have otherwise changed the drainage, so that much uncertainty attaches to the mapping of preglacial or interglacial drainage systems.

In the following report of well sections appear many which have already been published by the Pennsylvania Geological Survey, as well as those collected by the writer:

The section of a well in the Chautauqua Valley at Jamestown, N. Y., reported by Gilbert D. Harris,[1] shows 220 feet of drift. The altitude of the well mouth is 1,325 feet. A well with similar altitude at Bemis Point reached a depth of 310 feet without entering rock.

For the Conewango Valley Carll has, in his report of Warren County, Pa.,[2] a tabulated record of the amount of drive pipe used in 42 wells along the valley from the State line southward to Warren. From this table it appears that the drift ranges in thickness from 50 to 270 feet. Fifteen of the 42 wells pass through over 100 feet of drift and 24 pass through 90 feet or more. It is Carll's opinion that the wells which show a relatively small amount of drift are not in the deep part of the ancient channel. They are all, however, in the valley bottom, the range in altitude of the well mouth being from 1,188 feet in Warren to 1,240 feet at the State line, with no wells between whose mouths are more than 20 feet above the level of the one at the State line. The valley floor shows a range from 964 to 1,162 feet above tide. The character of the drift is reported only for the well at the State line, where it consists of blue clay to a depth of 245 feet, below which is 25 feet of gravel and clay.

In the valley of Jacksons Run, near Chandlers Valley, a well sunk by

[1] Am. Geologist, March, 1891.
[2] Second Geol. Survey Pennsylvania, Rept. I^4, p, 309.

Henry Lawson penetrated 75 feet of drift, but several wells in Chandlers Valley strike rock at 20 to 30 feet.

In the valley of Little Brokenstraw Creek at Lottsville is a well showing an extraordinary amount of drift, 450 feet, and the well did not reach the rock. Carll furnished the following record.[1]

Section of Smith well, or Lottsville No. 2.

	Feet.
1. Surface loam and some gravel	8
2. River gravel, not coarse nor fine, medium	22
3. Quicksand	7
4. Clay, with some seams of quicksand and occasionally a few pieces of gravel pronounced to be limestone	163
5. Alternating bands of quicksand and fine and coarse gravel of many colors	200
6. Clay	30
7. Sand and gravel	20
Total	450

Authority, A. M. Smith, one of the owners.
Well mouth above ocean in feet (barometric), 1,410.

In connection with this section Mr. Smith stated that the record was given from memory, since they had thought to begin a written record when they entered the rock; but after driving 450 feet of pipe with no more indication of rock than at 35 feet, the undertaking was abandoned. In a footnote[2] Carll makes the following remarks concerning this deeply eroded valley at Lottsville:

It can not be questioned, however, that a remarkably deep valley was eroded here, and inasmuch as we have evidence in other places of deep cuttings that seem uncalled for on the theory of regular slopes to old stream beds, it suggests the inquiry whether the under ice currents, under certain peculiar combinations of circumstances, might not be capable of excavating in soft measures to a considerable depth below the level of the main outlet for the subglacial waters.

It is the present writer's opinion that this interpretation may be applicable to this and other valleys in which a remarkably low altitude of the valley floors near the inner border of the moraine have been found.

An analysis of clay from this well, taken from a depth of 150 feet, was made by A. S. McCreath at the State laboratory, and with it is given Mr. McCreath's analysis of clay from the "gravel pit" oil wells near Titusville.[3]

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[1] Second Geol. Survey Pennsylvania, Rept. I^4, p. 233.
[2] Ibid., pp. 234–235.
[3] Ibid., p. 235.

Analyses of clay from wells at Lottsville and Titusville.

	Smith's well.	Titusville.
	Per cent.	*Per cent.*
Silica	65.12	51.01
Alumina	15.939	20.93
Protoxide of iron	5.464	6.831
Lime	1.55	3.01
Magnesia	1.848	2.511
Alkalies	3.58	4.372
Titanic acid	.75	1.09
Carbonic acid and water	6.00	9.619
Total	100.251	99.373

Carll reports[1] drift at Spring Creek station, on Big Brokenstraw Creek, 137 feet thick, and near that station drift 200 feet. The structure is not made known.

A well at Major Mills's, 3 miles southeast of Spartansburg, was reported by J. Smith, of Union City, to have penetrated 214 feet of drift. Though in a valley the altitude is probably 1,600 feet. The drift consists of gravel and cobble in the upper 100 feet and of alternations of till, gravel, and sand in the remainder of the well section.

A well near the railway summit between Corry and Spartansburg is reported by White[2] to have penetrated 150 feet of drift. The well mouth is 1,575 feet above tide, or about 200 feet below the bordering uplands.

In Corry two wells at the Downer oil works, near the Erie station and at about the same level (1,431 feet above tide), are reported by T. A. Allen to have each penetrated about 175 feet of drift, the greater part of which is sand and gravel. Carll reports a well[3] at the Downer oil works which penetrates only 48 feet of drift; his authority is also T. A. Allen. There is possibly an error recorded in the present report, since Mr. Allen gave the thickness of drift from memory after a lapse of about twelve years.

In the east part of Corry a well was recently put down by Thomas Pine which penetrated 201 feet of drift and of which a careful record was kept. It passed through 16 feet of till and gravel at the top, below which

[1] Second Geol. Survey Pennsylvania, Rept. I^3, p. 29.
[2] Ibid., Rept. Q^4, pp. 36, 227.
[3] Ibid., Rept. I^4, p. 228.

is 185 feet of a blue gray clay or very fine sand, described to be "without grit." A soft shale was then penetrated to a depth of 13 feet, where water was struck which rises above the surface and forms a strong artesian well. The altitude of the well mouth is about 1,415 feet above tide.

White reports[1] a well 1 mile south of Concord, in Erie County, Pa., which penetrated 119 feet of drift. The altitude of the well mouth is 1,375 feet.

Along Oil Creek, in Crawford County, several deep wells have been sunk which penetrated heavy drift deposits, of which the following is a tabulated statement:

Table of wells along Oil Creek.

Location.	Thickness of drift.	Altitude of well mouth.	Altitude of rock floor.	Authority.
	Feet.	*Feet.*	*Feet.*	
Head of Oil Creek, north of Spartansburg	150	1,575	1,425	White.
Nickle's well, near Glyndon	75	1,310	1,235	Leverett.
Kinney's, 1 mile northeast of Centerville	100	1,270	1,170	White.
Phillip's, 1 mile northeast of Centerville	80	1,300	1,220	Leverett.
Well one-half mile northeast of Centerville	100	1,290	1,190	White.
Centerville	60	1,290	1,230	Leverett.
Tryonville, near bridge	160	1,270	1,110	White.
Preston farm, below Tryonville	200	1,265	1,065	White.
Gray's well, below Tryonville	160	?	?	White.
Reed estate, above Hydetown	190	1,240	1,050	White.
Gray's well, above Hydetown	226	1,260	1,034	Carll.
Bartlett's well at Hydetown	180	1,240	1,060	Leverett.

In the well records collected by the writer assorted material constitutes the bulk of the section; in those collected by the geologists of the Pennsylvania survey the character of the drift is not reported.

On the uplands west of Hydetown, at an altitude about 300 feet above the creek, there are wells which have a larger amount of drift than is common outside the main valleys. They are on a small tributary of East Sugar Creek. One on F. B. Schreiner's farm penetrated 190 feet, and one on Mr. Totham's farm 178 feet, and a second one on the same farm 60 feet of drift. These were reported by Mr. Aikin, of Hydetown, who assisted in drilling them. Mr. Aikin states that they show a much larger amount of drift than

[1] Second Geol. Survey Pennsylvania, Rept. Q^4, p. 234.

is commonly met with, the rock usually being struck at 30 feet or less on the uplands. A well at Mr. Mosier's, 2 miles northeast of Townville, in a lowland tract near the head of Muddy Creek, has 125 feet of drift.

White notes[1] a well with 130 feet of drift on East Sugar Creek in southeastern Crawford County near the outer border of the moraine. The altitude of the well mouth is 1,260 feet. Several other wells along Sugar Creek between the moraine and Coopertown penetrated 100 feet or more of drift. The well mouths are, as a rule, but 15 to 20 feet above the creek. At Coopertown the drift extends about 60 feet below the flood plain of the creek, and at the mouth of Sugar Creek near the Venango Infirmary, at a level about 1,000 feet above tide it extends but 30 feet below the present flood plain, as shown by several wells. White reports[2] a well with 80 feet of drift on West Sugar Creek near Sugar Lake.

In the valley of French Creek several wells show a large amount of drift. White mentions[3] a well 4 miles below Meadville, which penetrated 285 feet of drift and did not reach rock, though 265 feet below the present stream and at the bottom only about 800 feet above tide. Carll in several places[4] refers to a well near that locality (which is perhaps the same one) by which he was enabled to fix the level of the rock floor at 800 feet above tide.

A well at Valonia, a suburb of Meadville, sunk by the Meadville Distillery Company in the autumn of 1891, shows a larger amount of drift than has been brought to notice elsewhere in the district covered by the Grand River lobe. It was reported by Xeno Putnam, of Harmonsburg, Pa., who obtained the statistics from the well driller. The well is about one-fourth mile above the junction of French and Cussewago creeks and midway between the two streams. Its mouth is about 8 feet above French Creek, or 1,075 feet above tide. The following is the section as reported. Probably Nos. 1 and 2 are alluvium.

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[1] Second Geol. Survey Pennsylvania, Rept. Q[4], p. 180.
[2] Ibid., Rept. Q[4], p. 34.
[3] Ibid., Rept. Q[4], p. 167.
[4] Ibid., Rept. I[3], pp. 356, 357, 358, 359.

Section of drift in French Creek Valley near Meadville.

	Feet.
1. Soil (alluvium)	10
2. Drift (alluvium)	8
3. Gravel	27
4. Blue clay	30
5. Quicksand	325
6. Gravel	75
Distance to rock	475

The rock surface is therefore about 600 feet above tide and only 27 feet above the surface of Lake Erie. Putnam also reports a well made by Mr. Flood in the midst of the valley near the Meadville post-office which has 182 feet of drift. No other wells have been reported from the midst of the valley in Meadville, consequently the breadth of the deep portion is not known. Possibly there was excessive cutting here, such as Carll suggested for the Lottsville gorge (p. 454).

At Cochranton a well at the creamery penetrated 155 feet of drift without reaching rock. The altitude of the well mouth is 1,064 feet. The following is the section as reported by the well driller:

Section of well at Cochranton, Pa.

	Feet.
1. Gravel and sand with some cobble and bowlderets	40
2. Blue pebbly clay (till?)	105
3. Gray and blue sands, with gravel at bottom of well	10
Total depth	155

N. R. Pressler, of Cochranton, states that an oil well boring 4 miles below Cochranton, near the east side of the valley, on ground about 1,130 feet above tide, has 155 feet of drift, and another a few rods distant has 136 feet. From these wells a lowland tract connects toward the southeast with Sugar Creek Valley below Coopertown. This lowland or valley is interpreted to be the old channel of the Middle Allegheny discharging to the Lake Erie Basin, as shown in Chapter III.

About 4 miles northeast of Cochranton, in a small valley near Decker Run post-office, a well penetrated 71 feet of drift and obtained a flow of water from the rock at 78 feet. The drift in this well is nearly all gravel.

In the lower part of French Creek Valley, for 4 or 5 miles above its mouth, oil wells are very numerous, and so far as learned none of them pass through more than 60 feet of drift. The rock floor is 950 to 975 feet above tide, or 350 to 375 feet higher than it is 25 miles upstream at the distillery well near Meadville, reported above.

In northeastern Mercer County there is an extensive elevated tract in which the drift is, as a rule, 30 feet or more in thickness. On its surface bowlderets are very numerous.

In Big Sandy Creek Valley, at Polk Station (Waterloo), rock is struck at about the level of the creek bed, the thickness of drift being 30 to 45 feet. At Raymilton there are many borings for oil, and none of them show an ancient channel excavated below the level of the present creek bed. The greatest amount of drift penetrated in the village was in William Raymond's borings, which are on a terrace about 50 feet above the level of the creek. Two borings here penetrated 54 feet of drift. At James Winan's, 2½ miles above Raymilton, a boring near the creek passed through 87 feet of drift, striking the rock floor about 20 feet below the level at Raymilton. In the village of Sandy Lake, Hugh Baird made a well on a drift knoll at his residence, which did not reach rock at 120 feet. It was principally in blue till. At Stoneboro, on the south side of Sandy Lake, a well at the ice houses, 110 feet deep, did not strike rock, though it reached a level 40 feet below the level of the rock floor at Raymilton. From Sandy Lake a swampy valley leads west to Little Shenango Creek, whose summit is but a few feet above the level of the lake. Were the drift removed at the present divide its altitude would be lower than at Raymilton, and it is not improbable that in preglacial times there was a divide near that village, the valley being much narrower there than at Sandy Lake.

Along the Little Shenango the drift is of unknown depth. Mrs. Hadley's well at Hadley station, about 9 miles below the Sandy Lake Swamp, is nearly 200 feet deep and reaches a level about 100 feet below the creek and 80 feet below the rock floor at Raymilton, yet strikes no rock. No other records of deep wells along this stream were obtained.

On the uplands in eastern Mercer County and one-half mile west of Harrisville, near the outer border of the moraine, a well at Mr. Barnes's residence, 25 feet in depth, does not strike rock. It penetrates 8 to 10 feet of oxidized till, and then blue till to a depth of 23 feet, where a sand bed is reached. About 50 rods east of this is the eastern border of the moraine, and a rock ridge nearby rises to a height of 20 to 30 feet above the mouth of Mr. Barnes's well.

At Harrisville is a gravel plain formed as an outwash apron to the moraine. In it wells obtain water at 12 to 15 feet.

In Neshannock Valley east of Mercer the drift in an oil boring made several years ago was thought by citizens of Mercer to be fully 100 feet in thickness. In the valley of Neshannock Creek at Leesburg, in southern Mercer County, White reports[1] a well which penetrated 90 feet of sand and silt, reaching a level 80 feet below the creek.

In the west part of Newcastle Mr. Davison has a well 150 feet deep which extends to a level 50 feet below the Shenango River and does not reach rock; it is principally through till, but has some quicksand interstratified. In the north part of Newcastle there are heavy deposits of gravel which have a capping of till a few feet thick, some excavations showing a depth of 50 to 60 feet of gravel. The top of the gravel is about 900 feet above tide, or 115 to 120 feet above the level of the Shenango River. In the southern part of the city, on the east side of the river, many exposures of the drift are made in grading streets. They show an interbedding of till and gravel, the beds lying in oblique attitudes, rising usually toward the south. In one exposure the till is interbedded with a fine sand, and both are arched and disturbed. In this exposure considerable variation in the color of the till is displayed, some of it being a very dark blue, while both above and below it there is a yellow or brown till. In one exposure a thin bed of blue till rises toward the south and thins out, finally disappearing at a level about 15 feet above the northern end of the exposure, 2 or 3 rods distant. There are also exposures where poorly assorted gravel, cobble, and small bowlders are imbedded together in a matrix of sand. In the extreme south end of the city large gravel pits are opened, in one of which the following peculiar exposure was found: There is assorted material next the bluffs, the lower portion of which grades horizontally into till in the direction of the valley, and this till is overlain by gravel in contorted beds, as if disturbed by the ice sheet after deposition; yet this upper gravel has a nearly plane surface like a terrace.

White reports[2] a well in Newcastle, near the mouth of the Neshannock, made by Reis, Brown, and Bergher, which penetrated (1) gravel 15 feet, (2) blue mud and quicksand 125 feet, and here struck "slate." The altitude of the well mouth is 803 feet above tide. Mention is also made in a general way[3] of several deep drift sections from near the junction of the Mahoning and Shenango and along Beaver River.

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[1] Second Geol. Survey Pennsylvania, Rept. Q^3, p. 83. [2] Ibid., Rept. Q^2, p. 184. [3] Ibid., Rept. Q^2, pp. 13–18.

In the vicinity of Edenburg several wells were drilled at the time of the oil excitement of 1861 to 1864. They showed the existence of a broad deep valley there that in places extends 175 to 200 feet below the lowland tract along the river, or to a level scarcely 600 feet above tide. The significance of this deep excavation is discussed on pp. 150–151.

Near Mount Jackson, on the uplands west of Beaver River, at an altitude about 1,200 feet above tide, White notes[1] wells 40 feet deep as not reaching rock, and also[2] drift 30 feet thick on the uplands bordering Beaver River near Wampum at an altitude 275 feet above the stream. The latter point is very near the southern margin of the drift.

Near New Galilee the Pittsburg, Fort Wayne and Chicago Railroad has a large gravel pit, a brief description of which is given by White.[3] It has a depth of 60 feet and exposes "rounded bowlders of granite, limestone, sandstone, etc., together with fragments of coal and much coarse sand, filling up the intervals between the bowlders and also occurring in irregular lenticular masses by itself." The top of this pit is stated by White to be 130 feet above Little Beaver River. In the publication referred to, Professor White considered it a remnant of a terrace, but in a subsequent report[4] he considers it independent of Little Beaver River. His later decision is sustained by the fact that the moraine-headed terrace on this creek is but 15 to 20 feet above the stream at the point where it leaves the moraine.

In Columbiana County, Ohio, no wells showing a large amount of drift have come to the writer's knowledge. The general thickness on the uplands is as great as in western Pennsylvania, and it is probable that some of the valleys are deeply filled with drift.

In Mahoning County, Ohio, heavy drift deposits are exposed along the south bluff of Mahoning River, the thickness in places being as great as 75 feet. In the river valley several deep wells have been made which show a variable thickness of drift. Two borings at Niles were reported by Foshay to penetrate a large amount of drift; one at the Niles Rolling Mill has 190 feet, striking rock at a level about 170 feet below the river bed; the other at a farm house north of the city is 175 feet deep and does not reach rock, though it terminates at a level about 150 feet below the river.

Between Niles and the State line no borings in the Mahoning Valley

[1] Second Geol. Survey Pennsylvania, Rept. Q^2, p. 8.
[2] Ibid., Rept. Q^2, p. 7.
[3] Ibid., Rept. Q^2, p. 14.
[4] Ibid., Rept. Q^3, p. 17.

are reported which have so much as 100 feet of drift. One at Haselton has 90 feet as reported by Foshay, and 84 feet as reported in Geology of Ohio. At Lowellville the valley bottom is underlain at slight depth by rock, and the river has a rock bed. If a deep channel exists there it must be very narrow.

On the uplands south of Youngstown, in the vicinity of Boardman, borings for coal on George Baldwin's farm penetrate about 100 feet of drift, and on Emery Titus's farm near by, 90 feet of drift was penetrated, but on adjacent farms and in the village of Boardman rock is struck at slight depth. There is nothing in the topography at Baldwin's or Titus's to indicate an ancient valley, the altitude being about that of the general level of the uplands.

In Stark County wells on the uplands in the vicinity of Freeburg penetrate 30 to 40 feet of drift, mainly till; the thickness in the valleys is not known, the majority of wells being but 20 to 30 feet deep. In the interlobate moraine, a well at the elevator at Hartsville, in northern Stark County, 45 feet deep, does not reach rock. At Congress Lake, just north of Hartsville, the Cleveland and Canton Railway Company have driven spiles to a depth of 65 feet without reaching rock.

In Portage County several wells show a heavy drift deposit. At Firestone Brothers, 1½ miles northwest of Atwater, there is 145 feet, mainly assorted material. At Benjamin Whittlesey's, 1½ miles southwest of Atwater, a well 139 feet deep does not reach rock. In Atwater an uncompleted well at the feed mill near the depot was down 78 feet at the time of the writer's visit and had not reached the bottom of the drift, but rock is near the surface in that vicinity. At Sandy Lake, near J. Cady's, a well strikes rock at 173 feet. The drift is mainly sand. At Campbellsport, 2½ miles southeast of Ravenna, a well on Richard Thompson's estate, 230 feet deep, does not reach rock. The altitude of the well mouth is 983 feet. In this well there was much blue quicksand in the upper 70 feet, below which was gravel and sand. Scarcely any till is struck by wells in this section. On the bordering uplands the drift is nearly all till. George Cline has a well, in the southwest part of Rootstown Township, 217 feet deep, which struck no rock, and so far as the writer could ascertain no outcrops of rock occur, and none is struck in wells within a radius of a mile. On the west side of the Cuyahoga, north of Kent, several wells show drift 175 to 300 feet

deep, but since these are located in the moraine west of the river they are more properly discussed in connection with that moraine. On the east side of the river from Ravenna northward the drift is not thick, and outcrops of rock are numerous. The greatest amount noted was 66 feet, in H. C. Babcock's well, in the southwest part of Shalersville Township.

BOWLDERS.

Over nearly the whole of this morainic system bowlders are a common feature on the surface, and they are to a considerable extent incorporated in the surface portion of the drift. A few places were noted where they are especially numerous, viz, near Salem, Ohio, along the inner part of the knob-and-basin portion of the moraine; in Beaver, Lawrence, and Mercer counties, Pa., in the outer part of the moraine, and along French Creek, in western Venango County, north of Utica. The bowlders seem to be scattered broadcast rather than confined to narrow belts.

CHARACTER OF THE OUTWASH.

In the description of the moraine, numerous references have been made to moraine-headed gravel terraces and gravel aprons which connect closely with the moraine and clearly represent the outwash from it. These terraces in most cases merge at their heads into the gravelly knolls of the moraine. They usually descend somewhat rapidly for the first few miles, beyond which their slope is more gradual, differing but little from that of the present stream bed. They lead down the tributaries of the Allegheny to the main stream, and thence down to the Ohio and along that valley as far down as the mouth of the Muskingum, where contributions from the Scioto lobe have been received.

The material is so coarse as to indicate a current of considerable strength. It is coarser than that readily transported by the present streams except in their flood stages, and seems to indicate that the streams then had at times a volume fully as great as the present greatest flood stages. The silt and fine sand, which are now such conspicuous ingredients in the flood plains of the Ohio and Allegheny rivers and their tributaries, were swept away from their glacial valley deposits; as a consequence, the glacial terraces are composed largely of gravel, some of which is very coarse.

These deposits bear clear evidence that the valleys which they occupy had been opened to their full depth at this stage of glaciation, otherwise there could not have been a free discharge through them.

STRIÆ.

The following list of striæ embraces not only those within the limits of this morainic system, but also all that have been observed by the writer within the area of the Grand River lobe, together with those previously reported in the Ohio, Pennsylvania, and other geological reports or papers. Some cross striations occür, and some which do not bear toward the moraine, but, taken as a whole, the trend is outward from the Lake Erie and Grand River basins toward the moraine, even in the most hilly portions of the district.

Table of striæ.

Location.	Bearing.	Observer.	Observation or publication.
Panama, N. Y., 4 miles north of	N. to S	Carll	Report I[3], p. 64.
Corry, Pa., 1 mile south of	S. 45° E	Chamberlin	Notes of 1882.
Meadville, Pa., 2 miles east of	S. 35° to 38° E	Leverett	Notes of 1890.
East of French Creek, opposite Conneaut outlet.	S. 62° E	Leverett	Notes of 1890.
Meadville and vicinity (general)	S. 30° E	White	Report Q[4].
Evansburg, hills southwest of	S. 32° to 35° E	Leverett	Notes, 1890.
Near Adamsville	S. 37° to 58° E	Carll	Report I[3], p. 48.
Near Adamsville	SW	Carll	Report I[3], p. 53.
East Fallowfield Township, Crawford County.	S. 30° E	White	Report Q[4], p.144.
East Fallowfield Township, Crawford County.	S. 30° to 40° E	White	Report Q[4], p. 146.
East Fallowfield Township, Crawford County.	S. 35° E	White	Report Q[4], p. 146.
East Fallowfield Township, Crawford County.	S. 30° E	White	Report Q[4], p. 147.
Snodgrass Run, near Jamestown, Pa.	S. 50° E	Leverett	Notes, 1890.
J. O. Anderson's quarry, east of Jamestown, Pa.	S. 10° W. to 18° E	Leverett	Notes, 1890.
Milledgeville, hill south of	S. 70° E	Leverett	Notes, 1890.
Utica, hill 2 miles northwest of	S. 80° E	Leverett	Notes, 1890.
Near Raymilton	SE	Wright	Report Z, p. 179.
Big Sandy Creek	SE	White	Report Q[3], p. 166.
Greenville, 4 miles east of	SE	Leverett	Notes, 1890.

Table of striæ—Continued.

Location.	Bearing.	Observer.	Observation or publication.
Near Salem Church, 4 miles southeast of Greenville.	SSE. and SE	White	Report Q^3, p. 190.
Near Salem Church, 4 miles southeast of Greenville.	S. 8° to 50 E	Leverett	Notes, 1890.
Southwest part of Hempfield Township, Mercer County.	S. 20° E. and SE	White	Report Q^3, p. 190.
Greenville, hill west of	S. 28° E	Leverett	Notes, 1890.
Orangeville, State line south of	S. 55° E	Leverett	Notes, 1890.
Near State line, southwest of Sharon	N. to S	White	Report Q^3, p. 122.
Sharon, 2 miles south of	S. 12° E	Leverett	Notes, 1890.
Sharon, 4 miles south of	SE	White	Report Q^3, p. 98.
Sharon, hill east of	S. 20° E	White	Report Q^3, p. 108.
Mercer, 2 miles east of	SE	Leverett	Notes, 1890.
Near Newcastle	SE	White	Report Q^2, p. 8.
Near Rock Point, in Beaver Valley	SSE	Foshay	Bull. G. S. A., 1890.
Bartholomew's quarry, 5 miles southwest of Andover, Ohio.	S. 10° W. and S. 25° E	Leverett	Notes, 1890.
Farmdale (on Sugar Creek)	S. 10° E	Leverett	Notes, 1890.
Vernon Township, Trumbull County, Ohio.	S. 20° to 40° E	Read	Vol. I, p. 530.
Burg Hill	SSE	Carll	Report I^3, p. 434.
Brookfield	S. 50° E	Whittlesey	Vol. V, p. 770.
Hubbard, 1½ miles northeast of	S. 10° E	Leverett	Notes, 1890.
Youngstown	N. to S	Newberry	Vol. III, p. 782.
Near New Lisbon	N. to S	Miller	A. A. A. S., 1866.
Fowler Township, Trumbull County	S. 4° to 45° E	Read	Vol. I, p. 530.
Cortland, 1½ miles southeast of	SSE	Carll	Report I^3, p. 434.
Cortland, 1½ miles southeast of	S. 10° E. to 8° W	Leverett	Notes, 1890.
Warren, Ohio, 3 miles north of	SSE	Carll	Report I^3, p. 436.
Austintown	S. 35° E. to 31° W	Whittlesey	Vol. V, p. 770.
Lordstown Township, Trumbull County.	S. to S. 20° E	Whittlesey	Vol. V, p. 770.
Braceville Township, Trumbull County.	S. 45° to 50° W	Whittlesey	Vol. V, p. 770.
Farmington Township, Trumbull County.	S. 30° W	Whittlesey	Vol. V, p. 770.
Thompsons Ledge, Geauga County	S. 52° W	Leverett	Notes, 1890.
Thompson Township, Geauga County.	S. 50° E. and S. 40° to 50° W	Read	Vol. I, p. 530.
Mountville Township, Geauga County.	S. 40° W	Read	Vol. I, p. 530.

Table of striæ—Continued.

Location.	Bearing.	Observer.	Observation or publication.
Parkman Township, Geauga County	S. 30° W	Whittlesey	Vol. V, p. 770.
Near Welshfield	S. 58° W	Leverett	Notes, 1890.
Kennedys Ledge, Portage County	S. 10° to 14° W	Leverett	Notes, 1890.
Nelson Center, Portage County	SW	Colton	Notes, 1890.
Garrettsville, 1 to 2 miles southeast of.	S. 55° to 86° W	Leverett	Notes, 1890.
Palmyra	S. 30° W	Newberry	Vol. III, p. 135.
Edinburg	S. 60° W	Newberry	Vol. III, p. 135.
Hiram, 1 mile south of	S. 18° to 30° W	Leverett	Notes, 1890.
Hiram (college grounds)	S. 40° to 62° W	Colton	Notes, 1890.
Hiram, 1 mile south of	SW	Colton	Notes, 1890.
Chardon, 2 miles south of	S. 5° W	Leverett	Notes, 1890.
Chardon, 4 miles south of	S. to S. 12° W	Leverett	Notes, 1890.
Chardon, 2 miles southeast of	S. to S. 5° W	Leverett	Notes, 1890.
Leroy Township, Lake County	S. 45° W	Read	Vol. I, p. 530.

In the majority of the striated exposures, the bearings of which are given in the above table, no striking peculiarities were noted. The exposures are usually but a few square yards in extent and exhibit well-defined grooves of various sizes from an inch or more in breadth down to those more properly denominated striæ. Nearly all the striated exposures yet discovered are on the Carboniferous sandstone and conglomerate. Owing to the coarseness of texture of these rocks, they received few fine striæ, but coarse striæ are common, and glacial planing is very marked in many of the exposures. The occasional striæ noted in the above table, whose bearings are out of harmony with the general glaciation of the districts in which they occur, can not perhaps be wholly accounted for at the present stage of investigation, but it is probable that local topography exerted a measurable if not a controlling influence on the movement of the ice sheet at such places. No clear evidence was discovered that they were the product of a distinct ice invasion of a much earlier or of a much later date than the general glaciation.

J. C. Anderson's quarry near Jamestown, Pa., where an instance of cross striation was found, is situated on the north side and about 100 feet above the bottom of an east-west valley. There is a general glaciation, including glacial planing and grooves bearing S. 18° E., across which there

are scattered striæ formed subsequently, which bear S. 2° to 10° W. The rock surface dips southward; i. e., away from the advancing ice sheet. The later striation and possibly the whole glaciation may be due in large part to a sloughing of the ice from the quarry toward the valley, giving the striæ a more southerly course than the ice sheet had as a whole, for nearly all the striæ in the vicinity have a southeastward bearing.

At the exposure 4 miles southeast of Greenville, near Salem Church, where cross striæ occur, a projecting point of the east bluff of the Shenango River is glaciated. The glaciation where the Greenville and Mercer road crosses covers a part of the north slope, the crest, and considerable of the south slope of this ridge-like point. On the north slope and crest the striæ have a general southeasterly bearing, with variations of but a few degrees, but on the south slope great divergence occurs. About 20 rods south of the crest and 15 feet or so lower is an exposure in which the heavy glaciation is S. 17° E. About 20 rods farther south is a glaciated surface which descends southward with the slope of the hill, the descent being about 4 feet in a distance of 40 to 50 feet. The striæ vary from S. 8° to 50° E., the earlier and heavier glaciation being nearly southeast. The later glaciation varies from S. 8° to 35° E., and includes several large grooves. It consists of scattering striæ and grooves, with but little glacial planing, the earlier glaciation being but slightly effaced. The deflection toward the south on the south slope of this point of land may have been influenced largely by the lower land there. The absence of cross striæ on the north slope and crest seems to favor this idea.

In the quarries 1½ miles southeast of Cortland, Ohio, where cross striæ occur, there are two sets, an earlier, bearing S. 10° E., and a later, bearing about S. 8° W. The earlier is a heavy glaciation with grooves several feet long, the later a series of irregular gouges a few inches in length. This quarry shows signs of disturbance, the blocks in it inclining toward the west with a dip of several degrees. Whether or not the disturbance occurred while glaciation was going on, and whether, if it did take place at that time, the change of dip caused the change of bearing, the writer was unable to decide.

In Bartholomew's quarry, southwest of Andover, Ohio, the heavier glaciation is S. 25° E. The lighter glaciation, bearing S. 5° to S. 10° W., consists of scattering grooves. The relative ages of these sets was not determined, there being no place where both sets occur on a single surface.

The ledges southeast of Garrettsville, Ohio, which exhibit striæ ranging from S. 55° to 86° W., do not present clear evidence that separate sets are inscribed, there being numerous striæ and grooves with intermediate bearings. This is also the case with the striæ at Hiram, Ohio, there being in the ledge west of Hiram College striæ at all angles from S. 40° to 62° W.

In the above table appear several cases of cross striation which were noted by the earlier observers, but which the writer has not examined.

INNER BORDER PHENOMENA.

GENERAL FEATURES.

The inner border district is limited in this discussion to the small area between this morainic system and the Cleveland moraine, the latter being described in a later chapter. This district is about 10 miles wide in Chautauqua County, N. Y., and Warren and Crawford counties, Pa., and 15 to 25 miles in Mercer County, Pa., and Trumbull, Mahoning, and Portage counties, Ohio, comprising in these counties almost the whole area drained by the Mahoning and Shenango rivers. Lying, as it does, adjacent to the outer morainic system, it presents nearly as much variation in altitude as the district covered by that system. The drift, like that in the morainic system, conceals to some extent the glacial ridges and valleys in the Ohio portion, but is insufficient to do so in the Pennsylvania portion because of the higher elevation and consequent greater depth of the river channels, though its thickness is as great as in Ohio. The drift in the valleys has great range in depth, as shown by borings at Jamestown and Fentonville, N. Y.; Lottsville and Corry, Pa.; French Creek Valley, near Meadville, the Shenango Valley at and below Greenville, Pa., and the Mahoning Valley at Niles, Ohio. There is an average depth of over 100 feet and an occasional depth of 450 to 475 feet. It seems probable that the Shenango Valley has throughout its entire length a narrow gorge filled to a depth of 125 feet or more, there being borings at Greenville, New Hamburg, Big Bend, Sharon, and Newcastle, all of which have between 100 and 150 feet of drift. In certain other valleys borings showing deep drift are very rare, but this does not disprove the existence of channels as deep as in the Shenango, for the valleys have not been adequately tested by borings. Indeed, it is probable that all the large valleys have throughout much of their course nearly as much filling as the Shenango.

The following table represents the deepest wells and sections of drift in this inner border district not previously mentioned:

List of wells with thick drift.

	Feet.
Greenville, Pa.,[1] D. C. Moyer's	127
Greenville, Pa., schoolhouse	122
Greenville, Pa., Dr. Leet's	120
Greenville, Pa., Mr. Packard's	122
Jamestown, Pa., N. E. Webb's, no rock struck	70
Big Bend, Pa., at tavern, no rock struck	112
New Hamburg, Pa., boring for gas in Shenango Valley	147
Transfer, Pa., drug store, no rock struck	60
Swamp south of Pymatuning station, no rock struck by spiles	100
Sharpsville, Pa. (see Rept. Q^3, p. 18)	63
Oakland No. 2, Mercer County, Pa. (see Rept. Q^3, p. 115)	110
Sharon Furnace, Pa. (see Rept. Q^3, pp. 118–119)	100
Middlesex, Pa. (see Rept. I^5)	136
Hubbard, Ohio, Loveless's livery stable	146
Hubbard, Ohio, rolling mill	140
Near Churchill, Ohio, prospect bore for coal, no rock struck	100
Churchill, Ohio, ordinary wells reach rock at	10–25
Kinsman, Ohio, at fair ground, no rock struck	137
Kinsman, Ohio, G. W. Burrill's, no rock struck	97
Braceville, Ohio, several wells, no rock struck	90
Cyclone, Ohio, Thos. Richard's, south of village, no rock	100

WEAK MORAINES.

This district is not entirely free from morainic features, there being portions of it that are strongly morainic, but on the whole the drift has a nearly plane surface and no well-defined belt of morainic topography traverses the entire district. At Corry, Pa., there are morainic features, and a moraine-headed terrace leads from Corry east to Big Brokenstraw Creek. This moraine does not have a well-defined continuation north or northeast from Corry, but is finely developed for several miles southwestward, with numerous knolls and sharp ridges 10 to 25 feet, and occasional ones 50 to 75 feet in height. There is a group of knolls, ranging in height from 30 to 75 feet, in a valley near Cook, in the southern part of Erie County, occupying a tract perhaps one-half mile square. A mile or so northwest of Cook is another cluster fully as large, situated on the slope of the valley. These knolls are at the southwestern end of the morainic belt. Southwest from this locality, in Crawford and Mercer counties, there is a general absence of morainic features on the uplands, but in several of the

[1] The Shenango, at Greenville, is flowing on a rock bed, the deep channel being east of the stream.

valleys drift knolls appear, and in places are as numerous as in the morainic tracts found in valleys farther north (described in Section IV, next chapter). Several valleys are more free from knolls for a few miles immediately north from the outer morainic system than they are at a greater distance. Thus in the Conewango Valley the bottom and slopes are very smooth from the inner border of the morainic system, nearly to Jamestown, N. Y., and there drift knolls appear. Along Oil Creek and its tributaries the valleys are quite smooth from the moraine to the sources of the creek. Along French Creek there are scarcely any knolls between the inner border of the moraine, 8 to 9 miles below Meadville, and Saegerstown, 5 miles above Meadville. On Conneaut outlet there are very few drift knolls, and the Shenango Valley, in Mercer County, is comparatively free from morainic features. On the uplands for 8 to 12 miles east from the Shenango, and in northern Mercer County, drift knolls are very rare.

In Ohio the greater part of Trumbull, the northwestern part of Mahoning, and the eastern part of Portage counties have a nearly plane drift surface, the principal exception being a morainic loop, described later, which encircles the Grand River Valley. There is outside the morainic loop a weak morainic belt, scarcely a mile in width, which the writer traced from Windham Center, Portage County, northward to Parkman, Geauga County, but could not trace farther south than Windham. It consists of a series of ridges and knolls, 10 to 25 feet high, among which are basins and sloughs. It perhaps represents a temporary halt of the ice margin, so slight as to leave perceptible traces along only a portion of its line.

ESKERS.

About 2 miles west of Sheakleyville, Pa., on comparatively elevated ground, near Mr. Porter's, is a sharp ridge about one-half mile long, 50 feet or more in height, and about 40 rods in width, with an east-west trend. So far as opened it consisted of gravel. Its form, trend, and structure indicate that it is an esker, but its connection with other ridges of this type is vague, and it has no fan at its eastern end.

In the valley of Sandy Creek, east of Sheakleyville, there are two low ridges side by side, each having a northwest-southeast trend and a form like an esker. Neither of them exceeds 40 rods in length, 10 to 12 rods in height, and 6 rods in width. It is probable that many small ridges of this kind exist which have escaped the writer's notice. Their trend being at

right angles with the moraine and in the direction of the ice movement, and their construction gravelly, they are regarded as small eskers.

The most prominent instance noted of this class of ridges remains to be described. Along Lackawannock Creek from its mouth, at the "big bend" of the Shenango southeast for 1½ miles, there is a large drift ridge 30 to 40 rods in width and 40 to 75 feet in height. It is quite continuous for about a mile, and extends in the form of disconnected knolls for one-half mile farther. The main ridge has knobs and basins along its crest and on its slopes. There are also along its south side occasional low drift knolls. The valley in which it lies is 100 to 120 rods wide (two to three times the width of the ridge). The surface of the ridge is gravelly, but no deep exposures occur. It is probably an esker, though it is broader and has a more hummocky surface than eskers commonly have. Its trend harmonizes with the ice movement, as shown by striæ in that vicinity. It does not connect with the moraine on the southeast, nor does it have an esker fan at its terminus. The valley in which it lies has its head within 2 to 3 miles southeast, on quite elevated upland, and there are few drift knolls in its upper course.

DRUMLINS (?).

In Lewis's report[1] is a description of a "rounded hill of compact till" lying in the Shenango Valley at Sharpsville. The description led the writer to suspect that it might be a drumlin, but an examination shows that its form is due to erosion, it having been cut off by ravines on the one side from the remainder of a quite extensive tract having the same altitude as the top of the hill, while its lower side faces a lower plain of the Shenango Valley. No drumlins were observed by the writer within the district covered by the Grand River lobe; but Chamberlin reports having observed hills with drumlin form in the vicinity of Corry, Pa., though they may have a rock nucleus.

TILL PLAINS.

The drift on the uplands is very largely till, and constitutes in Ohio a considerable portion of the "clay belt" or "dairy lands" previously described. The till is thickly interspersed with fragments of shale from the districts farther north. It has not the porous structure that characterizes the moraine,

[1] Second Geol. Survey Pennsylvania, Rept. Z, pp. 188–189.

even the elevated rock ridges of northwestern Pennsylvania having a sufficiently compact till coating to make the soil cold and wet. In the valleys of this district the drift is chiefly assorted material or a sandy till, as in the moraine, and for this reason the valleys often contain drier ground than the uplands.

TERRACES.

The Shenango Valley has at many points terrace-like benches 50 to 100 feet above the level of the creek, but these have not been carefully worked out and correlated. They were noted at Big Bend, where the height is about 50 feet above the stream; at Sharpsville, where it is about 90 feet, and below Newcastle, where two occur, one at 50 and another at about 100 feet. White notes[1] terraces between Sharon and Newcastle whose height is given as 20, 50, and 120 feet above the stream. As a rule these terraces are built up in a previously eroded valley, but below Sharpsville a terrace-like bench, 75 to 80 feet high, exists which has in part a rock platform and in part a substratum of till, only the upper portion being assorted material. This assorted material was evidently formed by a stream, but the head of the terrace has not been traced out. It is probable that careful study of the terraces on this and other valleys will bring to light a relationship between the streams which formed them and successive positions of the margin of the retreating ice sheet.

CORRELATION AND CHRONOLOGICAL POSITION.

The number of moraines in the Grand River lobe is much smaller than in any of the lobes farther west. The Cleveland and the Euclid morainic belts extend west only about to Cleveland, hence the outer morainic system and the fragmentary moraines between it and the Cleveland moraine are the sole representatives of the whole series in western Ohio, a series comprising not fewer than ten somewhat distinct moraines.

The small number is attributable in part at least to the coalescence of several moraines in the outer belt, and perhaps in part to an obliteration of certain moraines by later advances. Specific correlations with each of the moraines farther west are therefore scarcely to be expected.

In the shelf or shoulder between the Scioto and the Grand River lobe are two series of moraines, each comprising two or more members. The

[1] Second Geol. Survey Pennsylvania, Rept. Q^3, p. 95.

outer of these series sustains a position with reference to the glacial boundary analogous to that of the outer moraine of the Grand River lobe. The inner follows nearly the continental divide to the meridian of Mansfield, west of which its members become more widely separated and constitute the series that encircle the Maumee or western Erie Basin. It is thought that the outer of these morainic series is the correlative of the main portion of the outer morainic system of the Grand River lobe, while the series along the continental divide may be correlated with the fragmentary belts between the outer system and the Cleveland moraine and with the swell-and-sag tracts along the inner border of the outer system.

The result of detailed investigation has been to confirm in a remarkable degree the tentative correlation presented by Chamberlin in his paper on the Terminal moraine of the second Glacial epoch.[1] The evidence, so far as collected, sustains that correlation from Wisconsin to New York, though the fragmentary character of the moraines in western Indiana and eastern Illinois renders a full demonstration difficult.

In the less complicated districts of Ohio and eastern Indiana, where correlation with this system may be made with certainty by means of continuous tracing, it is found that moraines of different age from this system, both earlier and later, have contours strikingly different from it, none of them presenting, except locally, so sharply ridged or indented a surface. The Kettle moraine of Wisconsin is of the same type as the morainic system under discussion, and on that account, and in the absence of evidence to the contrary, is presumably to be correlated with it.

It is generally supposed that the outer moraine, mapped by Lewis, from the reentrant angle near Salamanca, New York, to the Delaware[2] is the correlative of the outer moraine of the Grand River lobe, but this correlation is not fully established. The writer's studies brought out no decisive evidence of difference in age. They were, however, carried but a short distance east from the reentrant angle.

That this outer moraine is very much younger than the high-level terraces of early glacial age, which occur in the valleys leading south from the glacial boundary in western Pennsylvania, seems beyond question, since, as already shown, the moraine-headed terraces which start from this

[1] Third Annual Report U. S. Geol. Survey, 1881-82.

[2] Described in Second Geol. Survey Pennsylvania, Report Z.

moraine indicate that the main valleys had suffered a large amount of deepening (200 to 300 feet) in the interval between the two ice invasions.

That much of the so-called "fringe" or sheet of thin drift lying between the Wisconsin morainic system and the glacial boundary is as old as the glacial material on the high-level terraces seems highly probable, since, as stated above, it presents a more aged appearance than that of the Wisconsin system. It also bears a strong resemblance to the attenuated drift border in other regions where the glacial boundary lies many miles outside the outermost well-defined moraine.

CHAPTER XIII.

MINOR MORAINES OF THE LATE WISCONSIN STAGE.

SECTION I. MORAINES OF THE MAUMEE-MIAMI LOBE.

UNION MORAINE.

The Union moraine constitutes the outermost member of a series of moraines which lie between the main morainic system of the Miami lobe (discussed in Chapter XII) and the Lake Erie Basin. It is more closely associated with, and bears a stronger resemblance to, the later moraines than it bears to the main morainic system. This moraine and the later ones present smooth or gently undulating ridges comparatively free from the sharp hillocks and basins which characterize the main morainic system. They have, however, a sufficiently undulatory surface to distinguish them from the bordering plains and have sufficient relief to greatly influence the courses of streams.

The breadth of these ridges differs in the different moraines. The Union moraine, the narrowest one of the series, has a general width of about 1 mile. The several moraines which lie between it and the Lake Erie Basin have each a general width of 2 or more miles, though locally they are crowded into narrower limits

DISTRIBUTION.

The description is taken up at Union, a town on the State line of Ohio and Indiana, from which the moraine receives its name. The moraine follows the north side of Greenville Creek in a course south of east to Greenville, Ohio, thence eastward to Bradford Junction, the portion between Greenville and Bradford Junction constituting the point or extreme southern portion of the morainic loop. The moraine bears north of east from the latter village, leaving Covington about 2 miles to the south and Piqua 3 miles to the southeast, and comes to the Great Miami River bluff about

midway between Piqua and Sidney. It follows the west bluff to the bend of the river at Port Jefferson, 5 or 6 miles above Sidney, having near Sidney a slight development along the east bluff. About 2 miles northeast of Port Jefferson, near Tileton post-office, it dies out in a plain, but is thought to find its continuation in a morainic belt a few miles to the east, which leads from near De Graff northward along the east side of the Great Miami to Lewiston, thence eastward along the south side of the Lewiston reservoir to the source of the Great Miami, in northern Logan County, where it becomes associated with the Mississinawa moraine, and in connection with that moraine passes into the Scioto Basin, the united belt forming the Powell moraine of the Scioto lobe.

From the State line at Union the moraine follows the north side of White River westward through Randolph County to Selma, in Delaware County. It there becomes broken up into loosely aggregated knolls and disconnected ridges, interrupted in places by plane tracts. Its limits are, therefore, difficult to determine. The outermost chain of prominent ridges leads from Selma northwestward to Royerton, beyond which no well-defined continuation was found, the surface being plane both to the north and west. An inner chain of ridges bears northwestward from near the Randolph-Delaware county line along the south side of Campbells Creek, determining to some extent the course of that stream. Its distance from the outer chain is 2 to 4 miles. This inner chain connects somewhat closely near Granville, Ind., with the Mississinawa moraine, though there is an interval of about a mile in the vicinity of the Lake Erie and Western Railway, where the surface is plane. In its northwestward continuation this belt is either combined with or concealed by the bulky Mississinawa moraine—at least no belt distinct from the Mississinawa was found.

Outside the two chains of ridges just outlined there are occasional developments of low knolls and short ridges along a line leading from Muncie somewhat directly toward Peru, passing near Alexandria, Point Isabel, Greentown, and Bunker Hill, connecting north of Peru with a bulky interlobate moraine formed between the Maumee and Saginaw lobes, but it is not certain that these undulatory tracts should be correlated with the Union moraine. Indeed, it is questionable whether so feeble a development of ridges and knolls merits classification as a moraine, though it may represent a line held by the ice margin for a brief period. As a tentative

correlation, it is suggested that the ice margin, at the time it was occupying the line between Muncie and Peru, held, farther east, a position essentially coincident with the Union moraine, and that, in its later shiftings, the ice margin fell short a few miles of reaching the western portion of the belt, but again occupied the portion from Delaware County eastward, and at that time formed the well-defined ridges which distinguish this eastern portion from the western. These ridges in Delaware County, Ind., become associated with the Mississinawa moraine, and are also combined with that moraine on the borders of the Miami and Scioto basins in west-central Ohio.

RELIEF.

From Delaware County, Ind., eastward the Union moraine, throughout much of its course, has an abrupt outer border relief. The inner border relief is somewhat less than that of the outer border, there being an accumulation of ground moraine material north of the terminal ridge. There is usually a descent of 10 to 20 feet from the crest of the moraine to the inner border plain, though in places there is no perceptible descent on the inner border, and the limits of the moraine are best determined by the change from undulating to plane topography.

RANGE IN ALTITUDE.

The Ohio portion of the moraine has but little range in altitude. Its highest points, which are in western Darke County, opposite the highland tracts of Logan County, stand 1,125 to 1,150 feet above tide, while its lowest points, which are along the southern curve of the loop between Greenville and the Great Miami River, have an altitude of about 1,000 feet. In Indiana there is a gradual descent from 1,125 feet at Union on the State line to about 925 feet at the junction with the Mississinawa moraine. In the feebly ridged tract outside that moraine the altitude of the uplands in the vicinity of the Wabash River is 750 to 800 feet, while the valley of that portion of the river stands only 650 feet above tide.

The rock surface has a range in altitude fully as great as the drift surface, there being as great an amount of drift at points where the moraine stands lowest as where it stands highest.

TOPOGRAPHY.

The contours of this moraine, as already observed, are of a smooth and gentle type compared with those of the knolls and ridges of the main morainic system. The main ridge rises somewhat abruptly above the outer border plain, but the undulations on its crest and slopes are low and gentle, seldom exceeding 15 feet in height. Basins are not a common feature except locally, as noted below.

At the northeast end in Logan County, Ohio, and westward from that point, in the portion of the moraine east of the Great Miami, there are many basins, some of which have abrupt bluff-like borders, while others are saucer-like, with a gentle rise on their borders. This portion of the moraine has not so well defined a main ridge as the portion farther west and has, on the whole, sharper contours. The knolls, however, commonly fall between 10 and 15 feet and seldom exceed 20 feet in height. The Miami River enters an elevated plain just west of De Graff, the altitude of which is 50 to 60 feet higher than portions of the moraine near De Graff, but the surface is remarkably free from drift knolls. Just west of Tileton and north of Port Jefferson the moraine reappears in considerable strength, there being a ridge or range of sharp knolls whose highest points stand about 30 feet above the bordering plains. This range continues sharp for only a mile or so, when the moraine assumes its usual surface expression, the knolls being 10 to 15 feet or less in height and the tendency to ridging not conspicuous. The little ridging that occurs commonly, though not always, takes the trend of the basement ridge which constitutes the bulk of the moraine.

A thin sheet of drift without definite ridging appears to have been deposited at this time on the plain east of the Miami, opposite Sidney, there being a small tract there with undulatory surface, and on its east border an abrupt descent of 10 to 15 feet to the outer border plain.

In the valley of Loramie Creek, near Lockington, basins as well as knolls are displayed. The knolls have a height of 10 to 20 feet and their contours are sharper than are those of the knolls on adjacent uplands.

For a few miles southwest from Loramie Creek the moraine is below its average strength and has not a continuous ridge, though a few short ridges with northeast to southwest trend occur. On the divide between the

Great Miami and Stillwater rivers, about 4 miles west of Piqua, the moraine assumes the form of a continuous ridge with gently undulating surface and holds this form westward to Delaware County, Ind. The majority of the swells have a height of 15 feet, but there are occasional swells that reach 20 to 30 feet.

The chains of ridges in Delaware County which connect this moraine with the Mississinawa are less easily described than the more closely aggregated portions of the moraine. The southernmost ridge of the outer chain bears away from White River, near Selma, curving around from a westerly to a northwesterly trend. It has a width of about one-half mile and a length of nearly 2 miles, its northwest terminus being in the northwestern part of sec. 6, T. 20, R. 11 E. Its highest points stand 25 to 30 feet above the bordering plains, while its general elevation is about 20 feet.

About a mile west of the northwest end of the ridge just described is the southwest end of an esker belt which trends north-northeast to south-southwest, and which is traceable from the borders of the Mississinawa moraine to this point. A description of this esker belt appears below. It terminates in a plain, the nearest morainic features being a ridge whose northern end, as noted above, lies a mile to the east. About 2 miles to the west is a ridge which probably constitutes the continuation of the moraine. It is nearly 2 miles in length and leads from sec. 27, T. 21, R. 10 E. northward to Killbuck Creek, in section 15 of the same township. At the northern end it makes a curve to the northwest. Its width is about one-fourth mile and its height 20 to 30 feet. Its surface has a gentle swell-and-sag topography. As already noted, no continuation of this ridge was found either to the north or west.

Passing to the inner line, we find it consisting in part of short ridges with east-southeast to west-northwest trend, among which there are small conical swells, and in part of a swell-and-sag tract free from distinct ridging. These ridges display a somewhat peculiar arrangement in the eastern part of Delaware County, in that they lap past each other and yet constitute but a single chain, a given ridge having its western end north of and extending slightly beyond the eastern end of its neighboring ridge on the west, indicating that its production was somewhat later than that of the ridge which it overlaps. From sec. 33, T. 21, R. 11 E., northwestward to the Mississinawa moraine there are no well-defined ridges; but there is, throughout much of

the distance, a series of knolls somewhat closely aggregated and of irregular form, standing 10 to 15 feet above bordering plains. On the north side of the Mississinawa River, near the point where connection is made with the moraine of that name, there are numerous basins inclosed among the swells, the topography being of a subdued knob-and-basin type for a mile or more south from the point of connection. This portion of the moraine borders an esker closely on the west. No decisive evidence was obtained as to its age compared with the inner chain of ridges just described. It lies inside the line connecting the outer chain of ridges, and is therefore, in all probability, of later date than that chain.

Before leaving this topic a brief description will be given of the feebly ridged tract leading northwestward from Muncie to the Wabash River, near Peru. Near Reeds, the first station on the Lake Erie and Western Railway west of Muncie, a slight ridging occurs with west-northwest to east-southeast trend, i. e., in line with that of the belt. There is also in this vicinity for 2 or 3 miles an abrupt rise of 10 to 15 feet or more from the plain on the south into the ridged belt. This is the only locality west of the meridian of Muncie where a well-defined relief was observed. Throughout the remainder of its course to the Wabash River this belt consists of swells, either isolated or in groups; whose height seldom exceeds 15 feet and among which there are nearly plane tracts that constitute perhaps one-half the surface along the line of the belt. The difference between this belt and the bordering country consists mainly in the greater frequency of its swells, for occasional swells 10 or 15 feet high are to be found on the bordering plains. Similar topography occurs on the uplands between the Wabash and Eel rivers, though the swells are more numerous and the expression is somewhat stronger than south of the Wabash. A peculiar sand ridge was found in this district which merits notice. It lies a few miles north of Peru, on elevated upland overlooking Eel River from the south, being mainly in sec. 29, T. 28, R. 5 E., but extending into the adjoining sections on the east and the west. Its trend is nearly due east and west. It stands 6 to 12 feet above the bordering country and is but 10 to 30 rods in width. So far as opened it consists wholly of sand, though lying in a district where the surface of the drift is till and being underlain by till at the level of its base. It more nearly resembles a beach line than a glacial formation, but no other evidence of the presence of a lake was discovered. Its origin, therefore, remains unsettled.

From the meridian of Peru eastward to the point where the Mississinawa moraine comes to Eel River (near South Whitley) there are occasional ridgings of the drift on the south side of this stream and nearly parallel with it, which have perhaps the same age as the ridged belt, though it seems more probable that they are older. The ridges are one-fourth to one-half mile in width and 10 to 30 feet high. They preserve continuity in some cases for 2 miles or more, but are usually a mile or less in length.

THICKNESS AND STRUCTURE OF DRIFT.

The thickness of the drift along the line of the Union moraine ranges from 20 feet or less up to 300 feet or more. This includes the drift deposited previous to the ice advance which produced this moraine as well as that of the moraine itself. The thickness as estimated by the relief of the moraine probably represents approximately the amount of material deposited during this ice advance and shows it to be on an average but 20 to 25 feet. A succession of till sheets beneath portions of the moraine near Sidney, Ohio (described below), also seems to indicate that the thickness was increased only a few feet by this ice advance.

In structure the predominant material is till, there being but few gravelly knolls and but little assorted material interbedded with the sheets of till. This moraine and the later ones of this lobe are locally known as "clay belts," to distinguish them from the plains between moraines, on which there is a black soil; but moraines and plains alike are underlain by till, and, with local exceptions, the till constitutes the soil and subsoil. The till differs from the deeper portions of the drift sheet only in the amount of weathering and the addition of humus. It is more clayey and compact and the soil less warm than in the main morainic system. In a few places surface bowlders occur in great number, but as a rule they are no more numerous on the surface than in the deeper portions of the drift sheet. In this respect this moraine differs from the main morainic system, on whose surface bowlders are more numerous than in the deeper portions; but it resembles the later moraines, none of which have (except in small areas) a markedly greater number of bowlders at the surface than in the body of the drift. It may be remarked in passing that the similarity between the surface and the deeper portions of the drift, the compact character of the till, and the gradual slope on the inner face of the moraine

each and all indicate that it is of the class which Chamberlin has termed a "lodge moraine,"[1] i. e., one formed from material carried in the basal portion of the ice sheet and deposited submarginally, rather than one formed at the actual extremity of the ice. If deposited at the margin it would seem to have been overridden and subdued by the margin of the ice sheet.

The records of wells and natural exposures here given are taken up at the eastern end of the moraine and followed westward.

In northern Logan County, from Big Springs westward nearly to the Lewiston reservoir, there are numerous outcrops of limestone, but among these outcrops are places filled deeply with drift, showing that the rock surface is very uneven. In the village of Belle Center there are extensive quarries, but one of the gas wells, scarcely one-fourth mile distant from the quarries and on slightly lower ground, penetrated 160 feet of drift, the greater part of the drift being till. Several flowing wells in and near this village obtain water from the drift, their depth ranging from 18 to 25 feet. The majority of them penetrate yellow till and then sand, each about 10 feet, after which they pass through a thin bed of blue hardpan, probably till, beneath which water-bearing gravel is reached. Some of the wells south of the village enter gravel at the surface instead of yellow till.

At Huntsville one of the gas wells penetrates 67 feet of drift, while rock is quarried one-half mile north of the village on ground fully as high as at the gas well. There are a few gravelly knolls in the vicinity of this village, but the drift penetrated in the wells is almost entirely till.

At Lakeview, near the outlet of the Lewiston reservoir, Mr. Angel has a well 112 feet deep which did not reach the rock. It passed through considerable quicksand. South of this reservoir for several miles the moraine contains many gravelly knolls, and the till which occurs is of a looser texture than in portions of the moraine farther west.

On a previous page attention was called to the great range in the thickness of drift at De Graff, one gas well reaching rock at 33 feet, while another one, a half mile north, penetrated 300 feet of drift before reaching rock. The drift is largely sand and gravel.

At Port Jefferson, in the Great Miami Valley, at a level but a few feet above the river and nearly 100 feet below the bordering uplands, a gas

[1]Bull. Geol. Soc. America, Vol. I, 1890, p. 28.

well penetrated about 350 feet of drift, striking rock at an altitude only 600 to 625 feet above tide.

At Sidney a gas boring near the Big Four Railway station, about 30 feet above the level of the river, penetrated 115 feet of drift, mainly sand and gravel, but only a mile south of the city rock appears in the river valley, forming bluffs 15 to 20 feet high. Outcrops of rock are frequent between this point and Piqua.

In a cutting made by the Big Four Railway, just west of the crossing of the Cincinnati, Hamilton, and Dayton Railway in Sidney, the following succession of till sheets is exposed:

Railway cutting near Sidney, Ohio.

	Feet.
1. Yellow till	12–15
2. Blue till	4–6
3. Yellow till	3–5
4. Blue till (exposed)	10–12

Near the standpipe in the northern part of Sidney, and nearly one-fourth mile distant from this railway cut, Nos. 1 to 3 are exposed, the thickness of the upper yellow till being 15 feet, and of the blue till 6 to 10 feet. The base of the lower yellow till is not exposed. It is probable that only the upper yellow and blue tills belong to the moraine under discussion, and that the lower tills are earlier. There is no striking difference between the rock constituents of the upper and lower sheets. In each sheet numerous pebbles of Lockport (Niagara) limestone occur, a large percentage of which are glaciated.

In the east bluff of the Great Miami, a mile south of Sidney, there are extensive exposures of cobble and gravel, above which there is a capping of till 10 to 12 feet in thickness. The cobble beds are in places so firmly cemented as to break through the pebbles more readily than around them. The pebbles are mainly Lockport (Niagara) limestone, but crystalline pebbles of Canadian derivation are not rare. A few bowlders a foot or more in diameter are embedded in the cobble deposit, so that it consists of an unusually coarse assorted material. In this exposure it is probable that only the capping of till belongs to the moraine under discussion, and the assorted material may either belong to an earlier advance or have been deposited just before the ice sheet covered the valley and deposited the till. In the west bluff, opposite the exposure of assorted material, there appears

to be till from top to bottom (nearly 100 feet), but exposures are not sufficiently extensive to enable one to fully decide this matter.

Bowlders are exceedingly numerous in the river valley just below Sidney, there being one field in which there are 1,000 or more per acre. At no other point along the upper course of this stream were they observed in such numbers.

No records of wells were obtained nor extensive natural exposures observed along the moraine between the Great Miami and the State line. The thickness of the drift in this portion of the moraine is seldom more than 50 feet, and several exposures of rock occur on its outer border along Greenville Creek. There are knolls along the south side of Greenville Creek, east of Greenville, which contain much assorted material, but also contain till. These, however, seem more likely to belong with the drift of the main morainic system than with the Union moraine. Bowlders are very numerous along Greenville Creek from the east border of these knolls (about 3 miles east of Greenville) eastward to the meridian of Bradford Junction, a distance of 6 or 7 miles. It seems not improbable that the bowlders are a dependency of the Union moraine. They are mainly small and well rounded, and thus differ from the bowlders which are scattered over the plains to the south, the latter being large and angular. The difference in size and angularity may, however, be accidental and indicate nothing as to separate ice advances.

At Greenville much variation in the thickness of the drift is reported, there being borings which pass through nearly 100 feet of drift, while near by, both on the east and west, outcrops of rock occur. In the vicinity of Union gas-well borings show a variation in thickness of about 160 feet. the greatest thickness of drift reported being 220 feet, while the least is 60 feet. In several borings for gas made within 5 or 6 miles of this city the drift was found to be nearly all till. In some borings a small amount of gravel was found just above the rock. In the well having 220 feet of drift, however, which is situated on the crest of the moraine, about 2 miles west of Union, there was but a small amount of till, as shown in the following section:

Drift penetrated near Union, Ind.

	Feet.
Till	40
Gravel	30
Sand	147

Near Winchester the majority of the wells penetrate from 80 to 150 feet of drift, but two wells $1\frac{1}{2}$ miles west of the city penetrated 332 and 333 feet, the first rock struck being shale (probably of Hudson River group). The drift is mainly quicksand, though some till was passed through.

In Farmland two wells, situated near the crest of the moraine, have each about 60 feet of drift, which consists of till, except a thin bed of gravel just above the rock.

A gas well at Selma penetrates the following drift beds:

Drift in gas boring at Selma, Ind.

	Feet.
Yellow till	12
Sand	8
Blue till containing streaks of brown sand	12
Sand containing a few pebbles	20
Fine gravel	25
Coarse and fine gravel in alternate beds	10
Total	90

The double chain of ridges previously described as leading northwestward from the eastern part of Delaware County into more or less close connection with the Mississinawa moraine is, so far as can be learned from exposures and borings, composed mainly of till.

Along White River near Muncie there are outcrops of limestone, and several of the gas wells in the eastern part of the city penetrate very little drift. Others on ground not more than 25 feet higher penetrate about 100 feet of drift. The thickness of the drift increases more rapidly toward the southwest from the outcrops of rock and therefore has no relation to the moraine under discussion.

There is a large gravel knoll and several small ones in the southwest part of the city of Muncie. It is not certain that they should be included in the Union morainic belt, since they lie slightly outside the line of the moraine, but a brief description of an exposure in one of them is here given. The largest knoll has been opened from top to bottom, and the excavation extends to the center or highest part. There is exposed a nucleus of till rising 20 feet or more above its base, around and over which the assorted material is deposited. The latter is very unevenly bedded, and in almost any vertical section several abrupt changes in the dip may be found. It is mainly a fine gravel composed largely of limestone pebbles, but on the western slope much sand occurs. This knoll rises about 40 feet above the

level of the surrounding country, and can not therefore be a product of erosion, but instead is a true glacial product, formed perhaps within or beneath the confinement of ice walls.

The records of a few wells along the line of the feebly ridged belt leading northwestward from Muncie are here presented.

At Alexandria rock is quarried in the bed of Pipe Creek. The drift in the gas borings is 22 to 28 feet thick, but the borings were made on ground standing 20 feet or more above the creek; the rock surface has therefore about the same altitude as in the outcrops. The following is the section of the boring near the Lake Erie and Western Railway station, in the southeastern part of the village:

Drift penetrated in boring at Alexandria, Ind.

	Feet.
Soil and gravel	6
Blue clay	16
Disturbed rock	6
Limestone, etc.	

At Summitville a gas boring was made on low ground west of the village at an altitude about 885 feet above tide, which penetrated 110 feet of drift, of which the upper 15 feet is yellow clay and the remainder gravel.

At Fairmount the gas borings penetrate less than 20 feet of drift. They are located in the valley of Back Creek, 25 feet or more below the level of the uplands. This valley is remarkably broad for so small a stream, and appears to have been formed by a subglacial stream leading southward, or the reverse of the present flow. The valley bottom and bluffs are lined with gravel, but a short distance back from the brow of the bluffs the drift appears to be mainly till.

At Point Isabel the gas boring is in a ravine and strikes rock at 22 feet. The drift is mainly sand. On the bordering upland, including the drift knolls, the drift is mainly till.

At Sims a well driller reported the following section of drift in the first gas well made in the village:

Drift in gas boring at Sims, Ind.

	Feet.
Yellow and blue till	22
Gravel	4
Blue till and bowlders	12
Gravel	6–7
Total	45

At Swayzee the drift has a thickness of 22 feet and is mainly till. At Switzer the thickness is 28 feet and mainly till. At Sycamore Corners the drift at the gas well, as reported by the driller, consisted of 15 feet of yellow and blue till, beneath which was 50 feet of gravel resting upon the rock. At Greentown the thickness of the drift in the gas boring is 85 feet; the exact section was not obtained. At Wawpecong, in Miami County, the drift is mainly till, and rock is struck at about 70 feet.

A gas boring at Bunker Hill, on ground slightly below the level of the station, penetrated 68 feet of drift, of which the upper 40 feet is till, and the remainder sand and gravel with thin beds of till. A well for water a short distance southwest of Bunker Hill has 84 feet of drift. Along Pipe Creek, within a mile below Bunker Hill, there are rock outcrops, but the valley is about 100 feet deep, and the altitude of the outcrops is nearly the same as that of the rock surface in the gas boring at Bunker Hill.

Along the southeastern portion of this feebly ridged belt bowlders are not a conspicuous feature, but in northern Howard and in Miami County they are numerous, and especially so in secs. 11 and 14, T. 24, R. 4 E., and east from these sections to the head of Deer Creek, which is in the ridged belt. The majority of the bowlders are large, 2 to 4 feet in diameter, and nearly all are of Canadian derivation.

STRIÆ.

The observations of striæ in the district comprised between the Union moraine and the next moraine to the north, the Mississinawa, are restricted to two in northern Logan County, Ohio, and to a single locality in Indiana. Nearly every rock outcrop was examined, but the surface is usually rotten and weathered to such an extent that striæ could not be detected had they once been present.

In quarries in the northeast part of Belle Center, Ohio, there are striæ bearing S. 10° W. They consist of very fine lines, confined to the prominent portions of the surface.

At a quarry one-half mile southwest of Richland, Ohio, there are striæ bearing S. 25° W. Here, as at Belle Center, they consist of fine lines, and are restricted to the prominent portions of the surface.

The observation in Indiana is at Alexandria, in Free's quarry, on Pipe Creek, just west of the railway bridge. The bearing is S. 39° W. (magnetic).

OUTER BORDER PHENOMENA.

The features of the upland portion of the district lying between this moraine and the main morainic system having already been discussed, it only remains to discuss the valley phenomena. The moraine is favorably situated for southward drainage, and the glacial waters appear to have had easy escape at several points. The gravel plains leading southward from this moraine are however not so large as from the main morainic system, but this is probably due to a smaller volume of the streams rather than to an obstruction to their escape.

The Great Miami appears to have been fed by glacial waters from the vicinity of De Graff, and also from the mouth of Loramie Creek a short distance above Piqua. The exact head of the stream which entered near De Graff was not traced out, but it appears to be located in the eastern tributaries of the Great Miami, no clear indications of glacial terraces having been found along the Great Miami itself above De Graff. The terrace material is, in large part, coarse gravel and cobble, well rounded, and is nearly free from the earthy material which occurs in alluvial terraces formed since the Glacial epoch. The altitude of the terrace from De Graff to the mouth of Loramie Creek is but 20 to 30 feet above the present stream, its usual altitude being about 30 feet. From the mouth of Loramie Creek southward nearly to Piqua there is a terrace standing fully 40 feet above the stream, but farther south it declines to 30 feet or less. Above the mouth of Loramie Creek the terrace has a smooth, flat surface, but for 2 or 3 miles south from the mouth of that creek it is traversed by shallow winding channels and has a somewhat undulating surface. This increase in height and change in appearance are thought to be due to the influx at that point of glacial waters that were heavily charged with sediment. There is an almost imperceptible gradation from the channeled and slightly undulatory terrace to the morainic knolls which occupy the lower course of Loramie Creek Valley. This appears therefore to be the beginning of a moraine-headed terrace.

Upon passing westward a few miles to the Stillwater River one finds a gravel plain of considerable extent where the stream leaves the moraine, about 2 miles north of Covington. The gravel deposits flank the outer face of the moraine, but southward become gathered into the limits of Stillwater Valley. This appears to have been the main outlet for the glacial lobe at the

time the Union moraine was forming, if we may judge from the size of the gravel plain, for it occupies at its head an area of several square miles. The thickness of the gravel deposit is but a few feet, there being rock at slight depth over much of the region upon which it rests. Places were observed near the borders of the moraine where the gravel is underlain by till at a depth of 12 to 15 feet. The altitude of the gravel plain at its head is nearly as great as that of the bordering till plains south of the moraine, and is at Covington 50 to 60 feet above the bed of Stillwater River, the stream here being in a narrow rock-bound gorge.

Greenville Creek also has a narrow gorge up to Greenville Falls, about one-half mile above its mouth. Its bed above the falls is mainly in the drift and its valley is less restricted and varies considerably in width. The gravel plain just described extends up Greenville Creek 2 miles or more and remnants of glacial gravel are found almost the entire length of the creek, but they are less conspicuous than the gravel plain near its mouth. The phenomena seem to indicate that the creek adopted its course along the outer border of the moraine because of a valley opened by glacial waters.

White River Valley carries but little gravel and has scarcely a sign of a glacial terrace along the portion which borders this moraine, its bed being but 10 to 20 feet below the bordering plain. It seems therefore to have been a subordinate line of discharge for glacial waters.

On the Mississinawa no terrace was noted which seemed to connect with this moraine.

INNER BORDER PHENOMENA.

The narrow tract lying between the Union and Mississinawa moraines, a tract nowhere exceeding 8 miles in width, consists mainly of a smooth-surfaced till plain on which the drift has nearly as great thickness as on the moraine into which it merges on the south. Two esker belts appear on this plain, one in Logan County, Ohio, between Richland and Huntsville, which is called the Richland esker; the other in Delaware County, Ind., leading from the vicinity of Greenville nearly to Muncie, which is called the Muncie esker.

THE RICHLAND ESKER.

The northern end of the Richland esker is immediately west of that village, from which point it extends in a south-southwest course for more than a mile without any serious interruption, and is continued in a chain of short ridges, with frequent gaps for nearly a mile farther. It lies in a valley

or esker trough which continues to the moraine at Huntsville, but the ridge itself falls short a mile or so of reaching the moraine. The esker has a width of 30 to 75 yards, including slopes, and a height in its northern half of 15 to 25 feet, but in its southern half its height seldom exceeds 10 feet. The trough in which the esker lies has an average width of 150 to 200 yards and is excavated only a few feet below the bordering plain, so that the higher parts of the esker rise above the level of the plain. The esker winds greatly, but the trough in which it lies has a trend nearly in line with the striæ of a neighboring quarry (S. 25° W.). In the northern half of its course the esker exhibits the great changes in direction indicated by the bearings given below, which are taken in order from north to south by a pocket compass: S. 5° W., S. 50° W., S. 35° W., S. 30° E., S. 10° W., S. 25° E., N. to S. The portion bearing S. 30° E. is but a few rods in length. The portion bearing S. 25° E. is somewhat longer, but the greater part of the esker bears west of south. The southern half of the esker consists of short ridges which form a chain trending northeast to southwest, but the gaps in the chain are very narrow. The esker appears to be composed of assorted material throughout its entire length. There is a railway gravel pit near its south end which exposes sand at the base of the ridge and gravel in its upper two-thirds. The beds present considerable arching and oblique arrangement. It is scarcely probable, however, that this one exposure can be taken as an index of the character of the beds in the whole ridge, for where eskers have been more extensively opened observation has shown hem to vary greatly in structure within short distances. The phenomena this esker and its trough, like those of eskers and esker troughs in general, lead to the conclusion that it was deposited by a stream flowing under the ice, that the stream had previously eroded the trough in which the ridge lies and had its discharge at the ice margin. The production of such a trough, and more especially of such a ridge, appears to demand a nearly stagnant condition of the ice sheet, or an exact balancing of movement and erosion, such as would prevent a filling of the trough and an obliteration of the ridge.

THE MUNCIE ESKER.

A brief description of the Muncie esker appears in each of Dr. Phinney's reports on Delaware and Henry counties, Ind.,[1] and through his kindness

[1] Eleventh Ann. Rept. Geol. Survey Indiana, 1881, p. 134; Fifteenth Ann. Rept. Geol. Survey Indiana, 1885–1886, p. 108.

the writer was conducted to the esker and spent a day examining it with him in the autumn of 1888. It is perhaps necessary to state that after this examination he found some slight errors in his later report, which he attributes to his having written it in part from memory. For example, the elevation of the esker is stated to be less than that of a clay ridge on the east. It was found that it stands considerably higher than the so-called clay ridge, and that the clay ridge is simply a bluff forming the border of the esker trough, its altitude being little, if any, above the plains to the east.

The Muncie esker sets in at the south border of the Mississinawa moraine, in secs. 33 and 34, T. 22, R. 11 E. It has, for one-half mile or more, a trend slightly south of west along the south border of the moraine just mentioned. It curves rapidly at the middle of the south line of section 33, to assume a southwest course. For 7 miles from this line its course varies but little, although within this distance the Mississinawa River passes through it in a narrow gap. Its southern terminus is in sec. 1, T. 20., R. 10 E. The esker has no well-defined trough or valley north of the Mississinawa, but is bordered on the east by a till plain and on the west by a morainic tract. South of the river it lies in a trough standing a few feet below the general level of the bordering country. The trough is several times wider than the esker and on each side is bordered by a narrow belt of drift knolls, the whole system, including the trough as well as knolls, being scarcely a mile in width. The esker is much more prominent than the knolls at its side. The esker trough finds a continuation with no deflection in course down the boggy valley of Muncie Creek to White River at the city of Muncie, but from sec. 18, T. 21, R. 11, to its terminus (in sec. 1, T. 20, R. 10 E.) the esker lies on the east border of the trough instead of in its deeper central portion. It has a range from 20 to 60 feet in height, and throughout much of its course the height is fully 40 feet. In the portion north of the Mississinawa the crest rises 20 feet or more above the morainic tract that borders it on the west and 40 to 60 feet above the plain on the east. South of the river the drift knolls that border the esker on either side are seldom more than 20 feet in height, and the esker here becomes a very prominent feature, which is visible for a long distance. The width of the esker is greater north of the river than south, but nowhere exceeds 200 yards, its usual width being 75 to 100 yards. A gap occurs where the Mississinawa River passes through, and there are two other gaps

farther south. One (in sec. 18, T. 21, R. 11) is scarcely 30 rods wide, but the other (in sec. 36, T. 21, R. 10 E.) is more than one-half mile in width. The southernmost ridge rises very abruptly at its north end to a height of fully 60 feet, but within one-half mile it becomes reduced to a height of 15 or 20 feet. Near its southern terminus it assumes a billowy topography, like that of a moraine, and contains much till. There is no delta or fan-shaped gravel deposit about this terminus, such as characterizes some eskers.

For several miles from its northern end the esker consists of gravel or gravelly sand with no coating of till, but southward from sec. 18, T. 21, R. 11 E., it carries a thin coating of till (2 to 5 feet or more), in which large bowlders are embedded, and at its southern terminus it appears to be composed mainly of till.

The portion capped by till has a less smooth surface than the remainder of the esker, but its form and trend are no different. It is perhaps less singular that an esker is occasionally capped by till than that the majority of eskers are free from it, especially if the esker be the product of a subglacial stream, as observations on eskers of existing glaciers seem to indicate,[1] as do also the phenomena of esker troughs.

A large portion of the pebbles in the gravel, probably 90 per cent, are from the Upper Silurian limestone of the region. This constitution of the gravel lends strength to the theory that the esker is subglacial rather than superglacial in its origin, for if superglacial it would presumably carry a larger percentage of material derived from a long distance.

The knolls along each side of the esker south of the Mississinawa River are in some instances composed largely of gravel, but in others nothing but till has been found. North of the river the morainic tract along the west side of the esker contains much till, and the plain on the east is underlain by till. Wells made near the foot of the east slope of the esker furnish evidence that the till passes beneath it, holding about the same altitude that it has on the plain.

The southern portion of the esker was apparently formed at the time the ice margin occupied the outer chain of morainic ridges leading from Royerton to Selma. Whether the northern portion was formed at the same time or subsequently was not satisfactorily determined. There appears

[1] Comp. Russell, Nat. Geol. Mag., Vol. III, 1891, pp. 106–108; also paper in Am. Jour. Sci., January, 1892.

to be no theoretical objection to the view that the segments of the esker were formed in succession from south to north, the southern end of each segment terminating at the ice margin, but the phenomena, so far as interpreted, do not bear clear evidence on this point. The inner chain of morainic ridges, along Campbells Creek, may have been formed before the completion of the esker, and it seems not improbable that the portion of the esker on the north side of the Mississinawa, if not all that lies north of sec. 18, T. 21, R. 11 E., is to be connected with this later ice margin.

The trough in which this esker lies consists of a broad, shallow channel leading from the Mississinawa Valley near Granville south-southwest to White River at Muncie, ranging in width from one-fourth mile or less up to fully 1 mile, and excavated to a depth of 10 to 25 feet below the level of the bordering till plains. A less sharply outlined valley leads from Muncie southward to the main morainic system. This valley is bordered on the west, throughout the greater part of its length, and on the east for a less distance, by low drift knolls and ridges which stand slightly above the bordering plains. This distribution indicates that they were probably produced in connection with the formation of the esker.

It is not certain that the excavation of the trough is restricted to the time during which the Union moraine was formed. The fact that it connects on the south with a similar channel that leads out to the main morainic system lends support to the view that the excavation began before the ice sheet withdrew from that morainic system. It seems probable, however, that a subglacial stream continued to occupy the northern end until the Union moraine was formed. There are in eastern Indiana other channels similar to the one under discussion, which have their southern ends in the main morainic system and extend back within the limits of later moraines. They strongly suggest a close succession in the development of moraines, with but little shifting in the course or position of subglacial streams. The other channels fall within the limits of the East White River lobe and will be discussed in a report covering that lobe. A short channel of this class, crossing the Union moraine just west of Selma, has attracted considerable attention because of the difficulties of constructing a railway across it.[1] This channel leads to White River and apparently finds continuation in a channel of similar character that extends southward from

[1] See Eleventh Ann. Rept. Geol. Survey Indiana, 1881, pp. 130–131; also Fifteenth Ann. Rept., p. 104.

White River to the main morainic system. The part of White River Valley crossed by this channel is very marshy. The excavation of this channel apparently began while the ice sheet still covered much of the White River drainage basin. Channels such as these promise important results when carefully studied.

MISSISSINAWA MORAINE.

DISTRIBUTION.

Under this name is described a morainic belt in part single and in part double, which throughout much of its course lies just north of the Mississinawa River, and which may therefore with propriety be named the Mississinawa moraine. After following the river from its source in Darke County, Ohio, westward to Wabash County, Ind., the moraine leaves the river and swings northward through the eastern tier of townships of the latter county, coming to the Wabash River at Lagro and to Eel River between South Whitley and Columbia City. In eastern Jay County the moraine consists of a single great ridge about 6 miles in width, but in western Jay County, and for about 20 miles west to the vicinity of Hartford City, it consists of a narrow outer ridge 1 to 2 miles wide, which follows the Mississinawa River quite closely, and a broader inner one 3 to 5 miles in width, the plane tract between them being 1 to 4 miles in width. Northwest from Hartford the two belts are united, and the moraine has a breadth of 5 or 6 miles.

The distribution of this moraine northward from Eel River is somewhat difficult to determine, inasmuch as it is for some distance associated with Saginaw moraines, the whole series constituting a part of the interlobate moraine between the Saginaw and Maumee lobes, whose course Chamberlin outlined some years ago.[1] Dryer considers a very rugged portion of the moraine, lying just east of the crest or in places constituting the crest in Whitley, Noble, Dekalb, and Steuben counties, Ind., to be the continuation of the Mississinawa moraine.[2]

The fact that the later moraines of the Maumee-Miami lobe are plainly traceable through the districts to the east of the interlobate moraine, and that the oldest of these later moraines (the Salamonie) in places touches the

[1] Third Ann. Rept. U. S. Geol. Survey, 1883, p. 330, and Pls. XXVIII and XXXI.

[2] Geology of Whitley and of Steuben counties, Ind., by Charles R. Dryer: Seventeenth Ann. Rept. Geol. Survey Indiana, 1889.

eastern border of the interlobate belt would seem to indicate that the continuation of the Mississinawa moraine lies within the interlobate belt, but the very strong contrast in topography between the terminal loop and the rugged portion of this interlobate moraine leads the writer to question whether the latter belt should be considered the continuation of the former. Were the evidence clear that the Saginaw and Maumee lobes were both in this field at the time the Mississinawa moraine was forming, conditions might have been favorable for producing this rugged belt and the striking change in topography, but all the evidence yet obtained from outwash and courses of glacial drainage apparently opposes the view that the Saginaw lobe was at that time occupying the western side of the Indiana portion of the interlobate moraine, and indicates that the western side was an open country free from ice, across which Pigeon River carried the waters from the melting Maumee ice lobe. The writer is inclined to believe that the continuation of the Mississinawa moraine is along a line outlined by Dryer as the course of the Salamonie or "Third Erie" moraine, both moraines being crowded into the one belt. This belt is much stronger than the portion of the Salamonie moraine immediately south of the Wabash River, where it becomes distinct from the Mississinawa moraine, and though somewhat less bulky than the terminal loop of the Mississinawa it may well be considered the equivalent of both moraines, since it was formed on the northwestern border of the ice lobe, where the movement would naturally be more feeble and the moraines less bulky than on the southern margin of the lobe. The course of this belt lies along the eastern border of the interlobate moraine from Columbia City to northern Dekalb County, passing just west of Garrett and Waterloo. It here swings eastward a few miles, then bears northward along the State line and enters Michigan near the corner common to Indiana, Ohio, and Michigan. Its course and connections in the latter State are under investigation.

East of the head of the Mississinawa, in Darke County, Ohio, the moraine is found to present a slight looping or southward projection in harmony with earlier moraines of the Maumee-Miami lobe. Its southernmost point is at Versailles, from which village its course is north of west to the head of the Mississinawa, and north of east to the divide between the Scioto and the Great Miami in southern Hardin County. On this divide it becomes associated with the St. Johns or Salamonie moraine on the north border and with the Union moraine on the south. The combined belt soon

enters the Scioto Basin, where it becomes differentiated into the Powell, Broadway, and Mount Victory moraines of that basin.

In the portion of Ohio west of the Scioto Basin this moraine seems not to have been recognized as such by the Ohio survey, though in the descriptions of the topography the rolling character of certain divides is mentioned.[1]

In Indiana the moraine was recognized by McCaslin within the bounds of Jay County,[2] while Dryer has mapped with much detail the portion from Whitley County northward to Michigan.

RELIEF.

The relief above the outer border plain ranges from 20 feet or less in the lower portions of the moraine to 75 feet or more where it is most prominent. The Ohio portion has, on the whole, a less bold relief than the Indiana portion. In Jay County, Ind., the relief falls below 50 feet, but in Delaware County, near Granville, it is fully 75 feet. In Grant County the crest stands 20 to 40 feet or more above the plain that lies west of the Mississinawa River. In Wabash County the moraine presents considerable relief, but it is inconspicuous, since the outer slope is long and gentle. Thus the altitude of the crest on the Chicago and Erie Railway, near New Madison, is 870 feet above tide, while the altitude of the plain west of the moraine at Bolivar, some 5 miles from the crest, is but 784 feet above tide. Where it borders the interlobate moraine its crest and highest points fall considerably below the crest of that moraine, though on the inner border they show a relief ranging from 20 to 60 feet above the border plain. It is somewhat distinct from the inner border of the interlobate moraine in Steuben County and there has a relief of 20 to 40 feet above the plain west of it and about the same above the plain on the east. In the double portion of the moraine in Jay and Blackford counties the plain included between the constituent ridges stands only 20 to 40 feet below the moraines on either side.

On the inner border there is a more gradual descent than on the outer, and the descent continues across the plain which intervenes between the moraine and the Salamonie River, so that at that stream the altitude is 50 to 100 feet lower than the crest of the moraine.

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[1] N. H. Winchell; Geology of Ohio, Vol. II, 1874, p. 411. A. C. Lindemuth; Geology of Ohio, Vol. III, 1878, pp. 496-498.

[2] D. S. McCaslin; Geology of Jay County: Twelfth Ann. Rept. Geol. Survey Indiana, 1882, pp. 155–156.

RANGE IN ALTITUDE.

This moraine displays scarcely any abrupt changes in altitude, since it traverses a comparatively smooth region, yet when taken in its entire length the range in altitude is considerable, for in its course from southern Hardin County, Ohio, around to the northeast corner of Indiana it crosses the Miami and Wabash basins and an elevated tract which separates them. In Hardin County the altitude along its crest is 1,100 to 1,150 feet; at the Miami Canal, in the Miami Basin, 925 to 940 feet; at and near the State line, on the high tract separating the Miami and Wabash basins, about 1,100 feet; at the Wabash River bluffs, near Lagro, 750 to 800 feet; in northeastern Indiana, about 1,050 feet. The following table presents the altitude of stations along or near the line of the crest of the moraine:

Altitudes along the Mississinawa moraine.

Locality.	Authority.	Altitude (above tide).
		Feet.
Silver Creek, Ohio	Cleveland, Cincinnati, Chicago and St. Louis Railway.	1,118
Anna, Ohio	Cincinnati, Hamilton and Dayton Railway.	1,018
New Berlin, Ohio	Miami Canal	948
Near Versailles, Ohio	Barometric	1,025
State line	Barometric	1,100
Near Ridgeville, Ind	Grand Rapids and Indiana Railway	1,053
Redkey, Ind	Lake Erie and Western Railway	966
Bowser, Ind	Fort Wayne, Cincinnati and Louisville Railway.	939
Upland, Ind	Pittsburg, Cincinnati and St. Louis Railway.	952
Near Van Buren, Ind	Toledo, St. Louis and Kansas City Railway.	885
Lagro, on Wabash River bluffs	Barometric	750–825
Lagro, Wabash River bed	Wabash and Erie Canal	667
Near New Madison, Ind	Chicago and Erie Railway	871
Eel River, at Liberty Mills, Ind	Wabash Railway	750
Columbia City, Ind	Wabash Railway	830
Churubusco, Ind	Wabash Railway	888
Laotto, Ind	Grand Rapids and Indiana Railway	882
Summit Station, Ind	Lake Shore and Michigan Southern Railroad.	1,001
Near corners of Michigan, Indiana, and Ohio	Estimated	1,500

TOPOGRAPHY.

This belt is seldom sharply morainic, but consists of swells or short ridges with gentle slopes, the rise on the slopes being 5° to 10° or less. The topography is, however, of a characteristic morainic type, the swells and ridges being of irregular form, independent of the present system of drainage, and interlocking in an intricate manner. There is, aside from the swells and short ridges, a basement ridge which is developed nearly continuously from the Miami Canal westward to the interlobate moraine in southern Whitley County, Ind., but is not so well developed from the Miami Canal eastward. It is this ridge which gives to the moraine its relief.

In places there are series of parallel ridges closely associated. Thus, south from Portland, Ind., there is a succession of ridges each trending east and west, or in harmony with the morainic belt, over which one rises, in a distance of 5 miles, to an elevation, just south of Bluff Point, of fully 130 feet above the Salamonie plain. Such ridges occur elsewhere along the moraine but are not the most common type of topography, swells and irregular-shaped elevations being far more common. These ridges often determine the course of creeks flowing from east to west or west to east in line with the trend of the moraine. The upper course of State Line Creek furnishes an illustration. Such streams eventually find a gap in the ridge which affords a passage either to the inner or the outer border plain. State Line Creek, for example, flows across the inner border plain into Wabash River.

The swells seldom exceed 25 feet, and are usually but 10 to 15 feet in height, but the surface is all more or less undulatory. Near Granville, Ind., however, in the vicinity of the northern end of the Muncie esker described above, there are knolls and basins with abrupt oscillations of 40 to 60 feet. The basins at the north end of the esker are, in several instances, fully 20 feet in depth, and are completely landlocked. Another prominent portion of the moraine overlooks Estey Creek from sec. 30, T. 22, R. 11 E. It stands 75 feet or more above the creek. North and west from Estey Creek the swells are only 20 to 30 feet higher than the creek.

North of Eaton a tendency to ridging in a north-northwest to south-southeast direction was noted, the ridges being 20 feet or more in height and 150 to 200 yards in width, and of various lengths, from one-fourth mile up to a mile or more.

As a rule the moraine has stronger expression near the outer border than on the inner. But in the vicinity of the line of Grant and Delaware counties it is feebly developed near the outer border, while back 2 to 4 miles there are larger swells, 20 feet or more in height. Near Upland there are swells 15 to 20 feet in height on the interfluvial tracts, and 30 to 40 feet high near the creek valleys. Here, as well as elsewhere in Grant County, features were noted in the vicinity of creek valleys which could not be the product of drainage erosion. The lowlands among the swells expand and contract in width to suit the form given them by the ice sheet. The postglacial streams have produced remarkably little modification of the glacial topography.

In Blackford County the moraine is crossed at nearly a right angle by a deep marshy valley leading southwestward from the Salamonie River near Balbec past Hartford to the Mississinawa near Wheeling. It has a breadth ranging from one-eighth up to one-half mile. The summit or water parting in the valley is near the line of the crest of the moraine, but the valley seems to have been deeply filled with peaty deposits there as well as elsewhere along its course. The most probable hypothesis yet suggested makes it the channel of a subglacial stream. Several other similar channels occur in eastern Indiana, as noted above.

In northern Grant and in Wabash County the moraine consists of swells, few of which exceed 15 feet in height, that occupy the crest and slopes of a ridge standing 30 to 50 feet or more above the plain west of it. In southern Wabash County this ridge constitutes the divide between tributaries of the Wabash and Salamonie rivers, and in northern Wabash County between the Wabash tributaries on its east slope and Eel River tributaries on its west slope. The surface is all more or less undulatory along the moraine, though the knolls are of a subdued form and contrast perceptibly with the plane surface west of the moraine.

In the portion of the moraine which borders the great interlobate belt there is a swell-and-sag topography with frequent oscillations of 10 to 20 and occasionally 30 to 40 feet, the whole surface being more or less undulatory. The portion traversing eastern Steuben County is also of this type, excepting a small tract in the southeastern corner of the county, where a lakelet known as Fish Lake occurs, which is surrounded by sharp knolls rising abruptly 40 to 50 feet or more above its surface. There are occasional shallow basins

along this portion of the moraine, but, like the terminal loop, it includes very few lakes, basins, and marshes.

In conclusion it may be remarked that the belt has throughout its entire length, from the Michigan line around to the Scioto Basin, and also in its continuation across that basin, very little variety in topography, and in this respect is unlike the interlobate moraine on its northwest border and the main morainic system of the Maumee-Miami lobe, both of which present a variable topography, ranging at frequent intervals from gentle swells to sharp knobs and basins.

STRUCTURE AND THICKNESS OF THE DRIFT.

The general thickness of the drift belonging to this moraine probably falls below 100 feet along the crest, and if the whole width of the moraine be considered, it falls below 50 feet; but this constitutes only a small proportion of the drift of this region. As shown by well records given below, the thickness in places is about 500 feet. In such cases the greater part is likely to be the deposit from earlier ice advances.

In discussing the structure, also, it is necessary to distinguish between the drift belonging to this moraine and that deposited during the earlier ice advances. Throughout nearly the entire length of this moraine assorted material constitutes but a very small percentage of the upper portion of the drift, or that portion produced by the ice sheet at its latest advance into this district. At earlier advances there appears to have been more assorted material deposited; at least the deep borings usually pass through a large amount. So far as this moraine is concerned, therefore, the drift is mainly till. It is oxidized to a depth of 8 or 10 feet, but the oxidation is light, the color being a grayish rather than brownish yellow. Below this depth the color is a grayish blue.

Bowlders are numerous, especially in Jay, Delaware, and Blackford counties, Ind. They are Canadian crystallines, but an occasional Paleozoic limestone occurs. In Jay County the bowlders appear to be more numerous near the inner border than on any other portion of the moraine, and in places abound on the plains just north of the moraine. The most conspicuous bowlder belt on this plain was observed between Salamonie, Ind., and Fort Recovery, Ohio. In Delaware County, Ind., there is a conspicuous bowlder belt on the outer border of the moraine along the Mississinawa River

Valley from Granville westward beyond Eaton, there being in the vicinity of Eaton, on the south side of the river, several fields where 50 to 100 bowlders per acre are to be seen. In the Ohio portion the moraine carries fewer bowlders at the surface than in Indiana. The number of bowlders along water courses and ravines traversing the moraine in the former region indicate that the deeper portions of the drift are about as plentifully supplied as the surface portion.

The following constitute the principal records of borings obtained along the line of the moraine. In many of the borings the exact thickness of each of the several drift beds passed through was not noted by the drillers, hence only general statements concerning the nature of the drift in such wells can be made.

At Jackson Center, in northeastern Shelby County, Ohio, a well at the Carter House 80 feet in depth does not reach rock. Its lower portion is through a blue-gray till. A sand bed was struck at about 30 feet, from which the water supply is derived. Near Anna, Ohio, two gas borings have been made, each of which penetrates nearly 500 feet of drift, the exact thickness in the one nearest the village being 490 feet. The altitude of the well mouth is about the same as at the Cincinnati, Hamilton and Dayton Railway station in Anna (1,018 feet above tide). The rock surface stands, therefore, little more than 500 feet above tide, though in a region where within a few miles the rock reaches an altitude of nearly 1,000 feet. It is probable that the boring was made in the line of an old valley, and the course of the valley, as traced by Bownocker, was toward the Grand Reservoir near Celina.[1] Many of the data by which this channel was traced appear in Orton's paper in the Nineteenth Annual Report of this Survey.[2]

Orton reported[3] 428 feet of drift in a gas boring at New Berlin, a few miles northwest of Anna and near the summit level of the Miami Canal (940 feet). Bownocker has also traced a channel from this point northward to the Grand Reservoir. Both to the east and to the west of the line connecting these wells rock is struck at an altitude of 900 feet or more. The character of the drift in the well at New Berlin is not noted. In those near Anna there was till for a few feet at the surface, but the great body of the

[1] Am. Geologist, Vol. XXIII, 1899, pp. 178–182.
[2] Part IV, pp. 711–716.
[3] Geology of Ohio, Vol. VI, p. 779.

drift is reported to be sand. Ordinary water wells in Anna 15 to 20 feet deep pass through the till and obtain water from the sand.

At Yorkshire, Ohio, 5 or 6 miles southwest of New Berlin, the drift is less than 100 feet in thickness, though near the crest of the moraine, while a few miles north, near the inner border of the moraine, its thickness is but 20 to 25 feet. The wells in the neighborhood of Yorkshire and at many points along the moraine farther west often have what is termed "bitter water." An analysis of such water from a well at Mount Pleasant, Jay County, Ind., is reported by McCaslin,[1] the analysis being made by Edward Haynes, of Portland, who also contributed the remarks following the analysis.

Qualitative analysis of "bitter water" from Mount Pleasant, Ind.

Free carbonic acid.
Carbonate of calcium.
Carbonate of iron.
Carbonate of magnesium (trace).
Sulphate of magnesium (epsom salts).
Sulphate of aluminum (trace).
Chlorides (trace).

The sulphate of magnesium existed in quite large quantities, and is undoubtedly the cause of the bitter taste of the water. The well-known cathartic "epsom salts" is sulphate of magnesium. To a sample of water similar in composition to the above, except that it contains no epsom salts, was added a small quantity of that substance (obtained from a druggist), and the result was a bitter water which could not be distinguished from the sample analyzed. Moreover, after all the other constituents of the water, save that of the sulphate of magnesium, were removed, the water still retained its bitter taste. The carbonates of iron and calcium existed in considerable quantities, and were held in solution by the free carbonic acid contained in the water. No test was made for phosphoric acid, as the necessary requisites could not be obtained in this place.

At Redkey, Ind., the drift in a gas well near the station is 73 feet, and is mainly blue till. A water well near the station penetrated only 63 feet of drift, but its altitude is probably 8 to 10 feet less than the gas well. At Como, 3 miles east of Redkey, a gas boring penetrated 80 feet of drift, mainly blue till. At Dunkirk the drift is mainly blue till, and gas wells enter rock at 60 to 75 feet. At Millgrove a gas boring penetrated 143 feet of drift, largely a blue till. In Hartford records of four gas wells were obtained whose drift thicknesses are 84, 87, 133, and 150 feet. In these

[1] Twelfth Ann. Rept. Geol. Survey Indiana, 1882, p. 171.

wells thin beds of sand and gravel are interstratified with thick beds of till. Tubular wells in Hartford and vicinity, made for the purpose of obtaining water, have, in several instances, passed through a heavy bed of till and then 10 to 20 feet of sand and gravel just above the rock, but in some wells the till rests upon the rock. At Van Buren records of two gas wells were obtained, in one of which the drift is 92 feet, while in the other it is 170 feet. The difference in altitudes of the well mouths is scarcely 25 feet. In a well 2 miles east of Van Buren the drift is 150 feet. At Lafontaine, just west of the moraine and 50 to 60 feet lower than its crest, a gas boring shows 300 feet of drift. It is probable that a preglacial valley was here entered, for the rock stands at a much higher level in all the neighboring wells.

Three wells on the moraine about 5 miles south of Lagro have struck rock at about 100 feet. Along the Wabash River near Lagro the rock rises not less than 70 feet above the river bed. North of the Wabash the drift is thicker than it is south, since the level of the underlying limestone becomes lower toward the north. At North Manchester, at an altitude scarcely 40 feet above Eel River, the gas boring penetrated 274 feet of drift. The drift here is almost entirely sand. Nearly all the wells in North Manchester are on a gravel plain and obtain water at 30 to 35 feet, but on the low ground along Eel River, in the eastern part of the city, are several flowing wells 60 to 70 feet deep which are mainly through till. It is evident from these wells that the general thickness of the valley gravel at North Manchester is but little greater than the height of the plain above the river. There may have been thin beds of till in the gas borings which were not noted; similarly, in borings where the drift is reported to be almost entirely till, thin beds of sand or gravel may frequently have been passed through, but on account of their thinness have occasioned no remark.

At Columbia City a gas boring was made near Eel River, on ground about 20 feet lower than the Pittsburg, Fort Wayne and Chicago Railway, which penetrated 224 feet of drift, the greater part being sand and gravel.

Four miles east of North Manchester, south of Eel River and on the moraine, a boring for water penetrated till 156 feet without striking a water-bearing bed. Several deep borings between Eel River and Lagro are reported to have been almost entirely through till. An exception was found in a well in sec. 16, T. 28, R. 8 E., where, after the yellow till had been passed through, a bed of sand was entered which continued to the bottom of the well, the depth of which was 90 feet.

There is a continuous gravel belt along Eel River above North Manchester to its source in Allen County. Much of the gravel was probably derived from the ice sheet at the time later moraines, which cross Eel River near its head, were forming.

The record of gas borings in the plane tracts which lie east of the moraine in Dekalb County are here given. The surface portion of the drift is probably contemporaneous with that of the moraine west of it, and earlier than the surface portion of the drift along the St. Joseph River. It is much to be regretted that accurate records of the various beds of drift passed through were not preserved, since light might thus have been thrown upon the number of drift sheets here represented. As already remarked, the thick drift here penetrated was probably deposited only in part at the time the Mississinawa moraine was forming, much of it being considered earlier than this moraine.

At Garrett the drift has a thickness of 318 feet. There is 50 feet or more of till at the surface, but below this fully two-thirds of the section is reported to be sand and gravel. Just above the rock there was found a clay of whitish color, in which no pebbles were observed. It was said to have been soft when brought up, but became hardened upon exposure.

At Auburn the drift in one of the gas wells has a thickness of 282 feet. The upper half is mainly till, but in the lower half sand predominates.

At Waterloo a reliable record was kept by the driller, as follows:

Drift penetrated in gas boring at Waterloo, Ind.

	Feet.
Yellow and blue till	40
Sand and gravel with but little till	270
Blue clay without "grit"	45
Gravel	10
Total	365

In a gas well in Butler the drift is 378 feet in thickness. The following section of the drift appears in Dryer's report:[1]

Drift penetrated in gas boring at Butler, Ind.

	Feet.
"Hardpan" (generally clay)	15
Gravel and coarse sand	275
Red quicksand	40
Clay (glacierite)	45
Cobblestones and bowlders	3
Total	378

[1] Sixteenth Ann. Rept. Geol. Survey Indiana, p. 103.

Dryer applies the term "glacierite" to the rock floor ground by the glacier and deposited in its drift. It is seldom free from admixture with coarse particles, but when thus free the term glacierite seems applicable.

In Steuben County two wells about 3 miles southwest of Metz each penetrate about 100 feet of till, and obtain water in sand and gravel at this depth. No other deep-well sections were obtained from the morainic tract in the eastern part of this county.

INNER BORDER PHENOMENA.

From the Wabash River northward the Salamonie moraine is somewhat closely associated with the Mississinawa on the inner border. In Blackford, Grant, and Huntington counties, Ind., there is between the Mississinawa moraine and the Salamonie River a level plain which is covered by till. The breadth of the plain in these counties is several miles. In Jay County, Ind., and Mercer and Darke counties, Ohio, the plain becomes reduced to a width of 2 to 4 miles, and farther east the Salamonie and Mississinawa moraines nearly coalesce. The till beneath this plain does not appear to be markedly different from the ordinary till of the moraines, either in texture or in the number, kind, and arrangement of pebbles. At present this plain is poorly drained, but it appears to have been crossed in the past by streams with better drainage conditions and also to have held lakes of small size on its most poorly drained tracts. Now these old water courses appear as sags and sloughs which are poorly drained, and the old lake bottoms are swamps which are seldom depressed more than 10 feet below the level of the bordering dry land. Open ditches are being made which follow the sags and find suitable fall to effect good drainage. From drainage maps in the office of county surveyor of Blackford County, at Hartford, it was learned that these ditches form a nearly perfect dentritic system of drainage with the creeks as their trunk, as if a more perfect system of drainage had formerly existed. A cause that has suggested itself to account for this change to less perfect drainage is found in the work of beavers. These animals may have cut down trees and formed dams which have greatly obstructed the drainage. In the absence of beavers fallen timber may have choked up the water courses. Many of the channels are excavated several feet below the general level of the bordering plain, and they are usually several rods in width. They have the appearance of abandoned ravines. The short time devoted to this territory did not give opportunity to obtain

full data concerning the character of the deposits in these channels. The few exposures observed in the district, however, showed a pebbly clay, which does not differ perceptibly from the till of the moraines.

OUTER BORDER PHENOMENA.

In northwestern Indiana the Mississinawa moraine, as interpreted by the writer, is closely associated on the outer border with the great interlobate Erie-Saginaw moraine, except for a few miles in Steuben County, where a plain intervenes. This plain is traversed from north to south by Pigeon River, and is commonly known as Pigeon River Valley. Its troughlike form is, however, not a result of excavation, but was produced by glacial accumulations on its borders, it being an intramorainic tract bordered by ridges which give it the false appearance of having been excavated. The width of this plain is 4 to 6 miles and the length 12 to 14 miles. Near its head are extensive gravel plains, and it is probable that Pigeon River constituted an important line of discharge for glacial waters at the time the moraine which borders it on the east was occupied by the ice sheet. The breadth and the deep excavation of the portion of this valley traversing the interlobate moraine give it every appearance of having been occupied by a much larger stream than the present.

The Wabash Valley probably constituted an important outlet for the glacial waters at the time this moraine was forming, but the great enlargement produced subsequently by the outlet of the glacial Lake Maumee has, to a great degree, effaced the terraces or other evidences of glacial discharge which may have been formed. In the city of Wabash, however, there is a terrace on which the court-house stands whose altitude is about 70 feet above the river, and this may be of the age of the Mississinawa moraine. It appears to be the upper terrace at that point. There is a rock shelf capped by a coating of gravel and cobble such as commonly characterizes the glacial terraces, but little earthy material being intermixed. The rock platform referred to appears to be the top of an old rock bluff, no rock of higher altitude having been noted in the bluff or border of the terrace north of the river. The shelf here produced is to all appearance excavated from drift material only, and does not represent the amount of work that would have been involved had it been excavated in the rock. From its border there is a gentle rise to the upland, whose altitude is 50 to 75 feet above the terrace.

Near Lagro, on the south side of the Wabash River, remnants of a terrace, standing 50 to 60 feet above the present stream, were noted on each side of the mouth of the Salamonie River. Their altitude seems to be too low to permit connecting them with the terrace at Wabash, yet no evidence of terraces at higher altitudes was found. It is possible that these terraces represent the stage of water in the valley at the time the Salamonie moraine was forming, and that the terrace at Wabash was formed by a stream whose head was below Lagro, since the outer border of the Mississinawa moraine crosses the Wabash River between Lagro and Wabash. A more detailed examination will, however, be necessary to determine the relationship of these terraces to each other and to the ice margins. Very little terrace material remains above Lagro, the valley having been swept clean by the waters of the lake outlet.

The Mississinawa River was very favorably situated to be an outlet for glacial waters from the Mississinawa moraine, its course being along the outer face of the moraine for many miles, and its discharge being unobstructed by the ice sheet or otherwise hindered. It does not, however, carry evidence of vigorous glacial drainage. Its valley, throughout much of the distance from the State line to southern Wabash County, follows closely the outer border of the moraine and occasionally enters it sufficiently for morainic knolls to appear on its southwest bluff. No gravel apron was found between the moraine and the river, and the river bluffs are, as a rule, composed of till from top to bottom. From the point where the river leaves the moraine, in southern Wabash County, to its mouth gravel deposits are more abundant than above that point, but no well-defined gravel apron or moraine-headed terrace was noted at the point of departure from the moraine. It seems necessary, therefore, to assume either that there was but little discharge of waters, or that there was such a balancing between the material contributed and the carrying power of the stream that but little material was deposited along its course. The valley is not large and may well be the product of a postglacial stream, a fact which goes to indicate that the discharge of glacial waters was light.

In the Ohio portion of the outer border district a broad swampy plain is found along the headwaters of Stillwater River, a stream which for several miles follows the outer border of the moraine. The plain carries no decisive evidence of vigorous glacial drainage. It is covered to a depth of 2 to 5 feet with a silty deposit, but does not appear to be underlain extensively

by gravel or sand. The stream leaves the moraine near Dawn. Eastward from this place to Swamp Creek, near Versailles, the outer border plain is not silt covered, but is underlain by ordinary till.

Just north of Versailles low gravelly knolls appear and constitute the outer part of the moraine. From this point a plain underlain by gravel leads southward along Swamp Creek Valley through Versailles, which seems to be an outwash apron. It carries a few shallow basins and sloughs, but is otherwise nearly plane. It stands 20 to 25 feet above the level of Swamp Creek and but little below the bordering till plains. Its width is about one-half mile and its east border is defined by a slough which leads from the moraine southwestward to Swamp Creek, separating it from the till plain, while the west border is determined by that creek. The gravel plain extends south only to the junction of the slough with the creek, or about 1 mile from the moraine. Farther south no terraces or remnants of the gravel plain were detected, both bluffs of Swamp Creek being composed of till. A well in this gravel plain, 34 feet in depth, at a street corner near the post-office at Versailles, was entirely through gravel, and so far as excavations have been made in the village the gravel appears to extend at least to the level of the bed of Swamp Creek. It seems somewhat remarkable, in view of the amount deposited near the moraine, that the deposition of gravel was not continued farther south in sufficient amount to leave traces along Swamp Creek Valley. Underneath the gravel the drift at Versailles is reported to be mainly till, the distance to rock being 120 to 142 feet.

Eastward from Versailles to Loramie Creek the outer border plain is underlain by till. Loramie Creek Valley was not examined sufficiently to determine whether or not it carries terraces connected with this moraine. Gravel deposits occur in small amount along the valley. East of Loramie Creek the Union moraine and the Mississinawa moraine are somewhat closely associated for a few miles. Farther east the outer border of the Mississinawa is vaguely defined, and there appears to have been no well-defined drainage lines leading from it to the Great Miami.

On the whole, therefore, the glacial drainage seems to have been less vigorous from this moraine than from the main morainic system. To what extent this is due to a depression of the land by which the grade of stream beds was lessened, and to what extent to a slower rate of melting and con-

sequent smaller amount of water in the valleys, is not determined. The general absence of silts on the plains outside the moraine is thought to indicate that the depression of the land could not have been sufficient to cause fluvio-lacustrine conditions, while the great excavation accomplished along the Wabash by the old lake outlet in the closing stages of glaciation indicates for that stream a rapid fall. The evidence, so far as gathered, does not bear out the view that the attitude of the land was the sole cause, and it is doubtful if it was the main cause, for the lack of vigorous drainage.

ST. JOHNS OR SALAMONIE MORAINE.

DISTRIBUTION.

This moraine succeeds the Mississinawa closely on the north in the terminal portion of the loop, being nowhere distant more than 10 miles, and usually not more than 2 to 4 miles. In the lateral portion, formed on the northwest border of the ice lobe, it is, as described in the preceding section, closely combined with the Mississinawa moraine.

The Ohio portion of the moraine was traced, about thirty years ago, by N. H. Winchell, and given the name St. Johns, because of its peculiarly strong development at a small village of that name situated a few miles east of Wapakoneta.[1] Portions of it were subsequently traced in Indiana by McCaslin[2] and Dryer,[3] the latter of whom gave it the name Salamonie, since it follows and controls the direction of that stream throughout nearly its entire length. The name Salamonie seems preferable to St. Johns, since it is not likely to be duplicated. Furthermore, it is of the same class as the names applied by Winchell and Gilbert to other moraines of northwestern Ohio and northeastern Indiana, being the name of the stream whose course it governs. Both names are, however, retained in the present discussion.

From the western border of the Scioto Basin, in Hardin County, Ohio, westward to the vicinity of St. Johns this moraine is closely associated with the Mississinawa, but westward from St. Johns a narrow plain separates the two morainic belts. This plain is occupied in turn by Pusheta Creek,

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[1] Proc. Am. Assoc. Adv. Sci., Dubuque meeting, 1872, p. 161; also Geology of Ohio, Vol. II, 1874, p. 405.

[2] D. S. McCaslin: Twelfth Ann. Rept. Geol. Survey Indiana, 1882, pp. 156–164.

[3] Geology of Whitley County, by C. R. Dryer: Seventeenth Ann. Rept. Geol. Survey Indiana.

Wabash River, and Salamonie River, the two streams first mentioned following it westward a few miles, then passing north through the moraine, while the stream last mentioned, as already noted, follows the outer border of the moraine through almost its entire course.

The following villages in Ohio are situated on this moraine: Waynesfield, Uniopolis, St. Johns, Fryburg, Botkins, New Bremen, Maria Stein, Chickasaw, Carthagena, St. Henry, Ferner (Oakland station), and Monterey. Fort Recovery is at its outer border. In Indiana the villages of Bryant, Balbec, and Keystone are situated on it, but its course is best outlined by a line following the north side of the Salamonie River. The moraine is well defined and has an average breadth of about 2 miles from the borders of the Scioto Basin in Ohio westward to southern Wells County, Ind., near the meridian of Bluffton. From this meridian northwestward to the Wabash River it is less well defined. It appears to be divided into two belts; the main one follows the northeast side of the Salamonie, while a weaker one follows the northeast side of Rock Creek. The profile of the Toledo, St. Louis and Kansas City Railroad displays both these belts as ridges with well-defined relief on either side, but their relief is less clearly appreciable by the naked eye, since the vertical scale does not have the exaggeration given it in the profile. Though the moraine is poorly defined in this portion of its course, the ice margin appears to have had at the time the outer belt was forming a position near the line of the Salamonie River, the country just north of the river being somewhat more undulatory than that south, though nowhere sharply morainic; while at the time the inner belt was forming the position was along the northeast bluff of Rock Creek for a few miles, thence northwestward along the south side of the Wabash River to Huntington.

North from the Wabash the outer belt, as above indicated, appears to be closely combined with the Mississinawa moraine. The inner belt follows Clear Creek to its source, north of which it is represented by a low ridge thickly strewn with bowlders, whose course in Whitley County, as determined by Dryer,[1] lies through the eastern part of Washington and western part of Union townships to southern Smith Township, where it becomes closely associated with the stronger moraine outside it, a moraine which

[1] Geology of Whitley County: Seventeenth Ann. Rept. Geol. Survey Indiana.

here includes both the Salamonie and the Mississinawa belts, and whose course was outlined in the discussion of the Mississinawa moraine.

It may be of interest to note the position of this moraine with reference to the great drainage systems. From the point where the moraine connects with the moraines of the Scioto Basin, near the head of the Scioto River in Hardin County, Ohio, westward to the Miami Canal, it follows, and to some extent constitutes, the divide between the St. Lawrence and the Mississippi drainage basins, but westward from the Miami Canal its course lies within the Mississippi Basin until the head of Eel River is reached, in northwestern Allen County, Ind. From this point northward it lies within the St. Lawrence Basin, and for a few miles in Steuben County it occupies the divide between Lakes Michigan and Erie.

RELIEF.

Where well defined, the moraine presents an abrupt outer border relief ranging from 20 to 50 feet and a ridge so nearly continuous that but few streams cross it. A few points along the crest of the ridge rise 75 feet or more above the outer border plain and 25 to 30 feet above the general level of the crest. On the inner border there is a nearly continuous descent for several miles from the crest of the moraine, but the relief is less apparent to the eye when approached from this border than from the outer border. The following altitudes taken from the profiles of railways crossing the moraine furnish precise data as to the relief on these lines:

Table showing relief of Salamonie moraine along certain railway lines.

Railway.	Inner border.		Crest (in feet).	Outer border.	
	Feet.	Location.		Feet.	Location.
Lake Erie and Western	913	Coldwater, Ohio	995	923	Fort Recovery.
Grand Rapids and Indiana	842	Geneva, Ind	955	904	Portland, Ind.
Fort Wayne, Cincinnati and Louisville.	820	Bluffton, Ind	895	865	Montpelier, Ind.
Toledo, St. Louis and Kansas City.	820	Bluffton, Ind	885	835	Warren, Ind.
Pittsburg, Fort Wayne and Chicago.	833	Arcola, Ind	877	830	Columbia City.

RANGE IN ALTITUDE.

This moraine shows no abrupt changes in altitude, since it traverses a nearly level country, but from the Wabash River, both to the north and to the east, it has a gradual rise. In the former direction the rise apparently continues into Michigan. In the latter direction the summit is reached near the head of the Scioto River. The following table, showing the altitude of railway stations and other points near the line of the crest of the moraine, serves to indicate the amount and rate of change in altitude:

Altitude along the Salamonie moraine.

Location.	Authority.	Altitude (above tide).
		Feet.
St. Johns, Ohio (knolls near village)	Barometric (Gilbert)	1,060
St. Johns, Ohio (main street)	Barometric (Gilbert)	1,008
St. Johns, Ohio (ravine in village)	Barometric (Gilbert)	964
Botkins, Ohio	Cincinnati, Hamilton and Dayton R. R	1,014
New Bremen, Ohio	Miami Canal	960
Maria Stein, Ohio	Barometric	950
Oakland station	Lake Erie and Western R. R	995
Bryant, Ind. (summit near)	Grand Rapids and Indiana R. R	955
Keystone, Ind. (summit south of)	Fort Wayne, Cincinnati and Louisville R. R	895
Warren, Ind. (summit east of)	Toledo, St. Louis and Kansas City R. R	885
Huntington, Ind. (Wabash Bluffs)	Barometric	800
Huntington station	Wabash R. R	734
Peabody, Ind	New York, Chicago and St. Louis R. R	837
Coesse, Ind. (summit near)	Pittsburg, Fort Wayne and Chicago R. R	877
La Otto, Ind	Grand Rapids and Indiana R. R	882
Sedan, Ind	Lake Shore and Michigan Southern R. R	923
Summit, Ind	Lake Shore and Michigan Southern R. R	1,001
Corners of Ohio, Indiana, and Michigan	Estimated	1,050

TOPOGRAPHY.

Considerable variation in topography is displayed by this morainic belt, portions of it being of the smooth ridge type with only gentle swells and sags, while other portions carry knolls of the sharpest type and of abrupt slope. The variations usually depend upon the structure, the portion in which till predominates being of a smooth or gentle type, while portions in which gravel or sand constitute the main material have sharp or abrupt contours.

In the vicinity of St. Johns, Ohio, the moraine for several miles presents a very sharp knob-and-basin topography with numerous knolls 30 to 50 feet in height. An esker ridge or chain of ridges occurs in this belt southwest of Fryburg, the trend of which is northwest to southeast, or nearly at right angles to that of the moraine. The chain is more than a mile in length, and the southeastern terminus is in a marshy plain near the outer border of the moraine. The esker has a general height of 15 to 20 feet and width of about 20 rods. It is along the line of this esker that Pusheta Creek finds a gap in the moraine through which it passes from the outer to the inner border plain. The gap as well as the esker was probably produced by the agency of subglacial waters. There are numerous low knolls bordering the esker and filling up and obscuring, to some extent, the trough in which it lies.

Near Botkins the moraine becomes feeble in expression, and for several miles west from that village consists of low knolls dotting a nearly plane surface, the knolls occupying less than half the surface and having a height of but 10 or 15 feet. Near Maria Stein the moraine assumes greater strength and from that village westward to the State line, and for 12 or 14 miles into Indiana, it has a somewhat uniform swell-and-sag topography. The knolls are low, usually falling below 20 feet in height, and with a few exceptions their slopes are gentle, but nearly the whole surface is undulatory.

Southwest of Balbec, Ind., a sharp belt of hills appears that follows the line of a valley or depressed tract which crosses the moraine from northeast to southwest. Several knolls rise abruptly to a height of 60 to 80 feet, and form a chain in line with and lying in the valley. They do not assume the peculiar ridge form of the esker, but are nearly conical. Their summits rise but little above the portion of the crest adjacent to the valley in which they lie, but their form shows clearly that the valley was excavated before the knolls were deposited in it, there being basins and sags completely inclosed among the knolls or shut in between them and the borders of the valley, while the slopes of the knolls are hummocky and irregular, as is the fashion in hills built up by the ice sheet, but which could not well be produced by drainage erosion. This valley is narrow (one-eighth to one-fourth mile wide) and nearly filled with the gravel knolls throughout its entire course, but it expands at the inner border into a broad, marshy

tract a mile or more in width, known as the "Loblolly," which is continuous from the moraine northeastward to the Wabash River. It is probable that this valley, together with the knolls deposited in it, is the product of subglacial waters moving southwestward toward the ice margin, the cutting of the valley having been accomplished prior to the deposition of the knolls; but both the excavation and refilling are thought to have been included within the time when the ice sheet occupied this moraine. McCaslin described this valley and its included knolls in his report on Jay County,[1] but did not ascribe its excavation and subsequent filling to a subglacial stream. Instead he assumed them to have been produced by a stream of postglacial age. He ascribed to this hypothetical free-moving stream an action such as no stream could have unless it had confinement such as was afforded by the ice sheet. Furthermore he supposed the stream to have continued southwestward across the Mississinawa moraine and then southward to "Collett's glacial river," a supposition that seems entirely unwarranted, for the Salamonie at that time afforded a lower outlet for the stream toward the northwest. As stated on page 449, an abandoned valley crosses the Mississinawa moraine along the line indicated, but this valley is thought to have been abandoned as soon as the ice sheet had withdrawn sufficiently to permit the waters to escape to the Wabash through the Salamonie River.

Northwestward from the sharp line of knolls just described the moraine presents for several miles a characteristic swell-and-sag topography, its swells rising with gentle slopes to a height of 10 to 20 feet. Between Keystone and Warren there is a nearly continuous ridge a mile or more in breadth whose crest and slopes are slightly undulatory and carry shallow basins as well as low swells. The ridge is easily traced beyond Warren to the vicinity of New Lancaster, but its crest and slopes are less undulatory than southeast of Warren. From New Lancaster to the Wabash River no definite continuation of the moraine could be found, though the surface of the country is slightly more undulatory than the plain south of the Salamonie.

On a preceding page an inner belt was stated to follow the northeast side of Rock Creek from near Keystone nearly to the mouth of the stream.

[1] Twelfth Ann. Rept. Geol. Survey Indiana, 1882, pp. 161–163.

This consists of a low, nearly continuous, ridge whose crest and slopes are scarcely more undulatory than are the adjacent plains. This inner belt appears to find its continuation in a tract with morainic topography which lies south of Huntington along the headwaters of Loon Creek. For several miles the creek flows among a series of knolls and ridges of morainic type, the highest points being 12 to 15 feet in height. There are also among these knolls a few basins.

The Wabash Valley for a few miles below Huntington contains a remarkably large number of bowlders. Their presence is thought to be evidence that the margin of the ice sheet overhung the valley at this point for a considerable period. In itself the presence of the bowlders here could scarcely furnish decisive evidence of the halting of the ice sheet, but when taken in connection with the morainic features which may be traced to the bluffs of the Wabash both from the north and the south they are of value as supplementary and harmonious evidence.

North of the Wabash, along Clear Creek Valley, the knolls and ridges are of a subdued swell-and-sag type, the highest knolls scarcely reaching a height of 20 feet. In southern Whitley County there are few knolls exceeding 10 feet in height, but Dryer has traced a bowlder belt northward from the head of Clear Creek to Eel River, and reports a well-defined smooth ridge along this line, which through a part of the distance forms a water parting between the Wabash and Eel rivers. As previously remarked, it is thought that this belt constitutes the continuation of the inner of the two Salamonie ridges traced to the Wabash from the south.

The combined Salamonie and Mississinawa moraines, leading from the Wabash River northeastward into Michigan, have, as already noted in the discussion of the Mississinawa belt, a swell-and-sag topography of characteristic though subdued morainic type.

THICKNESS AND STRUCTURE OF THE DRIFT.

The Salamonie moraine occupies throughout nearly its entire length a region heavily covered with drift. It includes but a small portion of this drift, since it rises but little above the level of the portion of the drift sheet outside it, which is evidently older than the moraine. Judging from the relief of the moraine we may conclude that it consists of a sheet of drift 20 to 50 feet thick along the crest. If the inner slopes be included the thickness is

probably less, though it is not certain how much filling occurred beneath the margin of the ice while it was forming the moraine.

This moraine presents, on the whole, a more variable structure than that of the Mississinawa moraine. Not only are gravel knolls more frequent among the till swells but there is a large amount of gravel and sand interbedded with the till sheets. A large part of the moraine, however, consists of ordinary till, such as constitutes almost the whole of the Mississinawa moraine.

Bowlders are fully as conspicuous as on the Mississinawa moraine, there being a sufficiently large number at the surface to supply nearly every farmer with material from his own farm for foundation walls for buildings and for other purposes. Along the Wabash River, near Huntington, and also in portions of the belt in Whitley County, they are so numerous as to be a great hindrance to the cultivation of the soil. They consist almost entirely of crystalline rocks (mainly granite) of Canadian derivation, but occasional Paleozoic limestones occur which are of less remote derivation. The bowlders are subangular to well rounded and but few of them show striation. The few that are striated testify, by the fresh appearance of the markings, that the general absence of striation can not be due to weathering. It is more probably due to transportation on the surface of the ice sheet, where glacial abrasion was ineffective. A large proportion of the pebbles in the till and gravel are limestone, derived from but a short distance to the northeast and thus are in striking contrast to the surface bowlders.

C. S. Arthur, of Portland, Ind., has collected many fossils from stones embedded in the drift of Jay County. They include Devonian, Upper Silurian, and Lower Silurian species. Among the Lower Silurian fossils the lamellibranch *Ambonychia costata* and the trilobite *Calymene blumenbachia* are said to have been identified. In discussing the occurrence of these fossils McCaslin suggests[1] that the ice sheet probably reached the Hudson River formation at a place north or east of the points where the fossils occur, and that, since the Upper Silurian limestone forms the surface rock over that portion of Indiana and the adjacent portion of Ohio, this formation must have been entirely removed by erosion in some undiscovered locality. A boring made at Geneva, Ind., in 1888, has demonstrated that

[1] Twelfth Ann. Rept. Geol. Survey Indiana, 1882, p. 164.

such erosion did occur, the first rock there encountered being Hudson River shale. This locality is east of north from the place where Lower Silurian fossils were found in the moraine, or in about the direction from which the ice was moving when the moraine was formed. It is, therefore, not improbable that the Lower Silurian fossils were gathered by the ice sheet but a short distance from the place where they were deposited. Whether they were gathered from the ledges at the last invasion or had previously been incorporated in the drift is not known, though the early incorporation seems more likely to be the case, since the altitude of the Hudson River rocks at this point is much lower than that of the moraine, and the earlier advance would presumably have filled up the channels which exposed this formation.

Since this moraine is situated near the continental divide in a portion of its course, and is crossed by few streams, the natural exposures are not numerous nor extensive. They are sufficient, however, to reveal the structure of the surface portion of the moraine. A few artificial exposures worthy of note have been made. One of these, in a large knoll at St. Johns, Ohio, is shown in diagram in an Ohio geological report.[1] The outer portion of the pit is represented to contain gravel in horizontal beds, while the portion nearer the center of the hill contains beds of sand and gravel which are inclined at an angle of about 70°. A diagram of a less extensive exposure in the same village appears on page 46 of the same report. In this exposure beds of gravelly hardpan (till?) occur, as well as sand and gravel.

In a gravel pit near the southeast end of the Foxburg esker the bedding is nearly horizontal. The pit is 12 to 15 feet deep and several rods in length. There is a coarse gravel and cobble at the top with finer gravel beneath. A short distance southwest of this pit a gravelly knoll is opened, exhibiting beds which dip from the east side toward its center. The dip of beds in the remaining sides of the knoll is not shown.

In the prominent range of hills near Balbec, Ind. (noted above), a gravel pit was opened at the time of the writer's visit in 1888, the excavation being at the southern end of the knoll. Its depth was about 30 feet and its length 50 yards or more. The beds dip toward the center of the knoll and arch considerably along a line at right angles with that connecting the pit

[1] Geology of Ohio, Vol. II, 1874, p. 45.

with the center, there being a double arch exposed in the lower beds upon which the upper beds rest unconformably. The greater part of the exposure, including all the arching beds, consists of fine gravel with much sand intermixed, but the highest part of the pit is a coarse gravel or cobble, dipping down funnel shaped into the hill to a distance of several feet, its point resting between the arches of the underlying beds of gravel noted above. At the side of this funnel there is an abrupt change to sand in horizontal beds. Such peculiar arrangements of beds as these glacial deposits present, both here and elsewhere, can scarcely be given a full interpretation in the present stage of investigation. They were probably deposited beneath the confining walls of a tunnel or cavity beneath the ice sheet, whose form was changing with the movement of the ice sheet. It is scarcely probable that free-moving waters in an open channel could produce wide and sharp variations in structure and dip, such as are here displayed.

Many of the wells in northwestern Jay and southern Wells counties have slight exposures of gravel. The gravel seldom constitutes the whole of a knoll, but is confined to one side, or forms a cone-shaped mass in its central portion with till around the borders. It was estimated that at least one-half the knolls in this portion of the moraine contain more or less gravel.

From New Lancaster to the mouth of the Salamonie there is much gravel in the immediate bluffs of the river, and the same is true of the bluffs of the Wabash River at and below Huntington. In places the bluffs have a thin capping of till, while the remainder of the drift consists of gravel and sand, there being the appearance of a fresh advance and a deposit of glacial material upon an old gravel plain. The gravel may occupy the divide in western Huntington County between these streams, but data from wells indicate that, if so, it is covered by a heavier deposit of till than that along the brow of the bluffs.

Along the Salamonie moraine and the plain north of it in Auglaize and Mercer counties, Ohio, wells indicate the presence of a deep channel which, as above noted, has been made a subject of special investigation by Bownocker. The channel is found to lead from Anna, in Shelby County, northwestward across the Salamonie moraine into the Grand Reservoir, where it was joined by a channel from the south which has been traced as far as Xenia. Bownocker traced the united channel northward from

the reservoir to the St. Marys River at Rockford, and also traced a channel from Rockford southwest some distance into Indiana. The latter channel passes under the Salamonie moraine near Camden. The rock floor of these channels is 400 to 500 feet below the present surface, or not far from 500 feet above tide. The bluffs rise to within 50 to 100 feet of the present surface.

The following well data, collected by the writer, serve to indicate the variability in thickness of the drift. At William Schroer's, about $1\frac{1}{2}$ miles northwest of New Knoxville, a gas well penetrated about 400 feet of drift, but a well at Mrs. Harman Schroer's, one-half mile nearer the village, penetrated only 280 feet, while wells north of William Schroer's penetrated scarcely 100 feet of drift. Three miles west of New Knoxville a gas well known as the "Hoewischer" well penetrated about 400 feet of drift, and a well at the east end of the Grand Reservoir penetrated 407 feet. Other wells at the east end of the reservoir show a smaller amount of drift, though one was reported to have penetrated about 350 feet. At the west end of the reservoir, near Montezuma, on Thomas McGee's land, a gas well shows about 400 feet of drift, and one a mile or so east of this well shows about 300 feet. Other wells are found within one-half to three-fourths of a mile from these which penetrated but 60 to 100 feet of drift. On the plain south of the Salamonie moraine, near the great cranberry marsh in southern Mercer County, a gas well penetrated 175 feet of drift. At Fort Recovery, also on the outer border plain, a gas well penetrated 145 feet of drift.

A well near Portland in sec. 18, T. 23, R. 15 E., Jay County, Ind., strikes rock at 83 feet after penetrating the following beds:

Drift in well near Portland, Ind.

	Feet.
Yellow till	15
Thin beds of sand	2–3
Blue till	65

A well 1 mile east, in section 17, penetrated 160 feet of drift, the log of which was not obtained. Another, a mile farther east and about a mile north of Bellefontaine, Ind., strikes rock at 80 feet. In these three wells the surface elevation differs but little. A well in the southwest part of section 7 of the same township strikes rock at 57 feet and penetrates till the whole depth of the drift. In the SE. $\frac{1}{4}$ of sec. 35, T. 24, R. 14 E., the drift has a thickness of 135 feet and is mainly till, there being a thin bed

of sand and gravel about 65 feet from the surface. This well was on lower ground than the one south of it in section 7, which strikes rock at less than half the depth. The rock surface in this neighborhood has a range in altitude of not less than 90 feet, while the drift surface varies scarcely 40 feet.

Wells along the pike east of Portland for about 4 miles strike rock at 45 or 50 feet. In some of these the upper portion of the drift is sand, in others a yellow till. The blue till is entered at 15 to 30 feet. In ditching or tile draining there are found to be abrupt changes from sand and gravel to till.

Borings for natural gas in the vicinity of Portland show considerable variation in the altitude of the rock surface, and consequently of the thickness of the drift, since the region is nearly plane. Notes concerning at least 20 borings were obtained, and in these the drift ranges from 40 to 160 feet in thickness. About 2 miles southwest of Portland, in sec. 30, T. 23, R. 14 E., there are rock outcrops in the valley of the Salamonie River at a level but 25 to 30 feet below that at the railway station at Portland.

Near the sharp gravel knolls which constitute the strongly morainic tract in western Jay County a well at Emery Gray's, in the NE. corner of sec. 30, T. 24, R. 13 E., penetrated the following strata:

Section of Gray's well, near Camden, Ind.

	Feet.
Yellow till	18
Blue till	128
Sand	9
Total	155

This well is just south of the valley in which the knolls lie, and is apparently in the line of the deep buried channel which, as above noted, Bownocker has traced from Rockford, Ohio, to Blackford County, Ind. A well at Mr. Branson's, north of the valley, and so near as to overlook it, is 125 feet in depth and is almost entirely through till. A well overlooking the water parting in the valley from the south side (in south part of sec. 19, T. 24, R. 13 E.) penetrated 74 feet of till before entering assorted material.

At Camden the first gas boring penetrated 41 feet of drift, as follows:

Drift in gas boring at Camden, Ind.

	Feet.
Bluish till	18
Gravel	22
Clay	1–2

North of Camden, along the Salamonie Valley, a deposit of gravel and sand overlies the till (No. "1" of the above section). It appears to be a dependency of the gravelly knolls of the moraine.

In Blackford County, in the vicinity of Montpelier, rock is exposed along the river valley and the gas borings penetrate but a few feet of drift.

In Wells County, in secs. 21 and 28, T. 25, R. 12 E., two wells each strike rock at 52 feet. They are on a low till ridge. A well at Nottingham, in section 34 of the same township, 72 feet in depth, does not strike rock. It is almost entirely through till. On a level tract in the west part of this township, in sections 19, 20, 29, and 30, several wells strike rock at 18 to 25 feet, while others much deeper do not reach the rock, showing that the surface of the limestone in that region is very uneven. Wells near the southeast corner of Huntington County and in the western part of Wells County, some of which are on the moraine and some on the inner border plain, are in several instances 40 feet in depth, and none of them strike rock. They enter a blue till near the surface, and this extends down to the water-bearing bed at the bottom of the wells. Mr. John McKee, a well-digger living near Warren, states that on the plain near the inner border of the moraine he often finds a bed of sand or gravel 4 or 5 feet thick just below the black soil which covers the plain. Rock is exposed along the Salamonie bluffs for several miles above Warren, and at intervals below that village. It also outcrops along the Wabash and some of its tributaries in Huntington County. It is probable, therefore, that the general thickness of the drift in these counties is about that of the height of the surface above these outcrops, which is but 50 to 75 feet.

The wells in Huntington County are shallow and seldom enter the rock. They usually pass through till until they enter the water-bearing assorted material near the bottom. On the south bluff of the Wabash River, in secs. 27 and 28, T. 28, R. 9 E., the following series of beds is exposed:

Exposure in Wabash River bluff in sec. 27, T. 28, R. 9 E.

Till	10–20
Sand and gravel	15–20
Limestone	10

Some of the gravel beds which are exposed just beneath the till dip perceptibly toward the west, but others are nearly horizontal. Those that have a dip terminate at their upper ends abruptly, as if truncated, and the till rests upon their upturned edges with a nearly horizontal under surface.

This exposure reveals, in places, a clayey gravel containing bowlderets, the whole intercalated between beds of assorted material.

Two miles north of Huntington, on the plain east of the moraine, a well struck rock at 112 feet, and another, 2 miles farther north, at 140 feet. In both wells the drift was almost entirely till. A well about 6 miles northeast of Huntington struck rock at 131 feet. Here also the drift is almost entirely till. A well 3 miles north of Roanoke, in southern Whitley County, 160 feet in depth, does not reach the rock. The bluffs along the old lake outlet from Huntington to Roanoke are composed mainly of till, sand and gravel being no more abundant there than on the uplands.

A well situated on the moraine, about 3 miles southeast of South Whitley (in sec. 1, Cleveland Township), failed to obtain water at a depth of 70 feet. It was entirely through till. Other wells in the vicinity are but 20 to 40 feet deep, and obtain abundance of water from beds of sand and gravel included in the till.

At Columbia City, as stated on a preceding page, the drift has a thickness of 224 feet while the general thickness from there northward into northern Michigan is apparently not far from 300 feet. For records of these wells reference may be made to the preceding discussion, pages 503–505.

INNER BORDER PHENOMENA.

Between the Salamonie moraine and the Wabash River, which in eastern Indiana flows parallel with and a few miles north of the moraine, there is a till plain, which as a rule is quite smooth and in places so very flat that the excavation of large open ditches has been found necessary to carry off the surplus rainfall. There is a general decrease in altitude from the moraine northeastward to the river, so that the crest of the moraine stands 75 to 100 feet or more higher than the bluff of the river.

This plain is covered with a deep black soil, and is timbered with beech, maple, elm, ash, etc., while the moraine carries much oak associated with the kinds of timber just mentioned. Oak is, however, less predominant than in the Mississinawa, Wabash, and St. Marys moraines. Exposures of the subsoil in this flat region are so slight that it is difficult to determine its character. In some places a silt or subaqueous clay was noted, but whether this deposit is of much extent was not determined. Such silts are often local and signify nothing as to general conditions of drainage.

Plains similar to that south of the Wabash River occur in Ohio, south of Beaver River and the Grand reservoir, and also south of the west-flowing headwaters of the St. Marys River. There is also a similar narrow plain in northeastern Indiana, between this moraine and the Wabash moraine. The latter moraine is nowhere, so far as yet traced, coalesced with the Salamonie. Yet it is nowhere distant from it more than 10 miles, and usually but 2 to 4 miles.

OUTER BORDER PHENOMENA.

As already noted, the Mississinawa moraine is closely associated with the Salamonie from the Wabash River in eastern Indiana northward as far as the study has been carried (to the Michigan line), but from the Wabash southeastward to Ohio there is a plain traversed by the Salamonie River, which makes an interval of 4 to 8 miles or more between the moraines. This plain stands at a lower elevation than the bordering moraines, and presents the appearance of a large valley when viewed from either moraine. That it was produced by the accumulation of drift in its borders and not by erosion was noted by McCaslin, who aptly remarks, in his report on Jay County, that its lower elevation, as compared with the moraine, is not due to erosion, for if such were the case it would be bowlder strewn, but bowlders are even more rare here than upon the moraine.

This plain does not carry a continuous coating of gravel and sand, though it appears to have been the line of escape for nearly all the water from the terminal portion of the ice lobe. Gravel and sand are, however, extensively spread over it near Portland, probably as a dependency of the moraine. At Camden, also, near the point where the belt of large gravel knolls in western Jay County comes to the river, there is a delta-like gravel deposit covering a square mile or more. Below Jay County the bluffs of the Salamonie have frequent exposures of rock ledges. The drift capping the ledges and occupying the depressions between them is mainly gravel, though places were noted where there is a capping of till. Whether the gravel is, in large measure, of earlier age than the moraine or is a dependency of it was not satisfactorily determined. The amount of gravel and sand along the Salamonie is much greater than is found along the Mississinawa or along the Wabash or St. Marys rivers. This is in keeping with the structure of the moraines that follow these streams, the Salamonie being far more plentifully supplied with gravel than any of the others.

SECTION II. MINOR MORAINES OF THE SCIOTO LOBE.

POWELL MORAINE.

This moraine is the outermost (and southern) of a series which crosses the Scioto Basin north of Columbus. It lies entirely within the drainage basin of the Scioto, bordering a lobe 35 or 40 miles in width and nearly 40 miles in length. There are in the shoulder east of the Scioto Basin only occasional local developments of morainic topography, but some of them may constitute the equivalent of this moraine. The cause of the lobation is readily found in the low altitude of the Scioto Basin compared with tracts either side of it, the axis of the basin being 200 to 300 feet lower than the eastern and western borders. It is thought to be a continuation of the Mississinawa moraine of the Maumee-Miami lobe since in position, structure, and topography it strikingly resembles that moraine.

DISTRIBUTION.

For several miles in the northwest portion of the lobe, on the high tracts in Logan County, this moraine is scarcely separable from the earlier ones, as it is pressed closely against them, and being of comparatively feeble expression can not be easily distinguished. It is therefore not practicable to trace completely a connection between it and the Mississinawa moraine. From the east side of Rush Creek, opposite Big Springs, it is traceable southward past West Mansfield to Mill Creek, being combined with a later moraine, the Broadway. The later moraine, which is probably a continuation of the Salamonie, bears eastward from West Mansfield along the north side of Mill Creek, while the moraine under discussion continues southward past East Liberty to the head of Darby Creek. It there swings eastward and follows the north side of Darby Creek to the bend north of Plain City. It continues eastward, crossing the Scioto immediately west of the village of Powell (from which its name is taken) and the Olentangy north of Westerville. Upon reaching Big Walnut Creek, near Sunbury, it turns abruptly northward and follows the west side of that stream to its source near Mount Gilead. From Mount Gilead northward to Shelby it apparently lies along the west border of the main morainic system, but can scarcely be recognized because of its feeble expression. For the same reason it has not been traced farther east into the shoulder east of the Scioto lobe.

The moraine is narrowest in its eastern limb, where its width is scarcely a mile. The remainder of the belt is 2 to 3 miles wide.

RANGE IN ALTITUDE.

The highest points on the moraine are in the northern part of the eastern limb where an altitude of 1,200 feet is attained. On the western limb few points exceed 1,100 feet. In the Scioto Basin the lowest points are slightly above 900 feet. The range in altitude, therefore, along the whole course of the moraine scarcely exceeds 300 feet. There is not an abrupt change in altitude as in the hilly districts, but a gradual rise from the basin to its borders. The following table, compiled from railway surveys, shows the altitudes of points on and near the crest of the moraine, beginning at the western rim and passing eastward along the moraine:

Altitudes along the Powell moraine.

Location.	Authority.	Altitude (above tide).
		Feet.
Pottersburg Station	Erie R. R	1,093
Summit near Marysville	Big Four R. R	1,038
Summit near Powell	Hocking Valley R. R	935
Summit north of Worthington	Big Four R. R	968
Sunbury	Cleveland, Akron and Columbus R. R	970
Near Marengo	Ohio Central R. R	1,155
Mount Gilead, summit in village	Barometric from Ohio Central R. R	1,150
Iberia	Big Four R. R	1,156
Galion	Big Four R. R	1,169
Summit near Crestline	Big Four R. R	1,177
East of Shelby	Barometric from Big Four R. R	1,140

RELIEF.

Where not combined with earlier ones this moraine has a well-defined and abrupt relief of about 40 feet on its outer border, and throughout much of its course has an equally great but less abrupt relief on its inner border. Several railroad profiles that cross the moraine had been examined before the writer visited this district, and from them a correct idea of the contour of the moraine in cross section was obtained. In places the outer border is so abrupt that upon entering the moraine the railroad is obliged to make cuttings. Such is markedly the case on the Hocking Valley Railroad south

of Powell, and less conspicuously on the Cleveland, Akron and Columbus and the branches of the Big Four Railroad. Field studies show that what is true of the points where railroads cross is true all along the moraine. The abrupt outer border makes it one of the most plainly marked moraines yet traced. There is, in many places, a rise of 20 feet in 100 yards in passing from the plain into the moraine, and in the portion south of Mount Gilead a rise of 35 feet is made in 100 to 150 yards, the moraine rising up like a bluff on the west side of Walnut Creek.

TOPOGRAPHY.

While the moraine is a conspicuous topographic feature when separated from other moraines, it becomes obscure when blended with them, for its constituent knolls lack sharp contours, such as characterize the knolls of the main morainic system. As a rule it presents gentle swells 10 to 15 feet or even less in height, covering 2 to 5 acres each. The surface is properly termed undulating and contrasts strikingly with the plane-surfaced tract on the outer border. It has not such contrast with the inner border tract, there being instead a transition from the decidedly undulatory, through gentle waves, to the nearly plane; but there is not on the inner border district quite so level a tract as on the outer.

THICKNESS AND STRUCTURE OF DRIFT.

So far as yet shown by well borings the drift does not present great variations in thickness, such as have been found to characterize the earlier moraines. The floor upon which it rests, though composed of several distinct kinds of rock, seems to be remarkably free from such inequalities as are common in the hilly districts bordering the basin. It is quite probable, however, that the basin is traversed by valleys which are filled with drift, but a general inspection of the surface does not reveal their position. The large streams have extensive rock exposures where they cross the moraine and also north and south of it. From these exposures and the knowledge obtainable from well records it is thought that the thickness of drift generally falls between 50 and 100 feet, but that it is less than 50 feet in the elevated part of the eastern limb and the extreme northern part of the western limb.

Natural exposures and wells alike show that the amount of assorted material is very small. The till, which constitutes the great bulk of the

moraine, is made up largely of a clay which becomes exceedingly hard when dry, owing probably to the small proportion of sand in it. The residents speak of the moraine as a "clay ridge." The bordering tracts present considerable flat surface with a rich, black soil, and accordingly are not classed by the residents with the clay beds, though they are usually underlain by till.

Many wells on this moraine obtain a bitter water, rendered so perhaps by the presence of magnesium sulphate. as was determined by analysis of water of similar taste at Portland, Ind., presented on page 502. The bitter water is most common west of the Scioto.

At Marysville a well at Robinson & Curry's planing mill struck rock at 100 feet, the drift section being mainly till. In the same village a gas-well boring near Mill Creek, on ground 20 to 25 feet lower than the station and 17 feet lower than the court-house grounds, passed through 50 feet of drift, as follows:

Drift penetrated in gas boring at Marysville, Ohio.

	Feet.
Creek wash and yellow clay	18
Sand and gravel	14
Blue till	18

This well has a strong flow of water from 145 feet below the surface, which will rise about 3 feet above the surface. At the town well in West Mansfield rock is struck at 100 feet. The section is mainly till. At New California the town well struck rock at 50 feet. It is characterized by bitter water. A well at N. W. Cochran's, one-half mile north of the village, also struck rock at that depth. Both well sections are mainly till. Winchell reported a well at this village, at S. B. Woodburn's, 54 feet deep, which does not reach rock and, like the town well, has bitter water.[1] He also presented[2] a list of 39 wells in Union County whose depths range from 11 feet up to 63 feet, none of which enter the rock. Of these, 4, situated on the moraine, are described as furnishing "bitter water;" 3 are chalybeate, 2 are sulphurous, and the remainder are mainly designated "good water." The deepest wells in this list are on the moraine; one at Mr. Smith's, at Pottersburg, being 60 feet, another, 2 miles east of that village, owner's name not given, 63 feet. At Newton, near the inner border of the moraine, the town well is 52 feet deep and has bitter water.

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[1] Geology of Ohio, Vol. II, p. 333.

[2] Op. cit., pp. 332, 333.

At Powell rock is struck at 70 feet, the drift being mainly till; but at Jerome, on equally high ground west of the Scioto, there are quarries in ravines in the midst of the moraine, the drift being only 25 to 30 feet thick. At Westerville, which lies just south of the moraine, rock was struck in the gas well at 94 feet. Wells on the moraine north of that village are only 30 to 40 feet deep and strike no rock. The well mouths in some instances have an altitude 60 to 75 feet above Westerville, but it does not follow that the drift is that much thicker than at Westerville, since the rock surface may have a lower altitude at that village than beneath the moraine. At Galena wells 50 feet deep do not reach rock, but at Sunbury, 2 miles northeast, rock is at the surface at an altitude fully 40 feet above the level of the well mouths at Galena. At J. N. Lawren's, 1 mile northwest of Sunbury and at lower altitude than the quarry, a well 33 feet deep does not strike rock. At Marengo wells 40 feet deep do not reach rock. They scarcely reach the level of the base of the morainic ridge on whose crest the village stands.

Winchell gives a list of 28 wells in Delaware County in which the drift ranges from 6 to 56 feet in depth. Of these 5 are sulphurous and 6 chalybeate. The remainder are mainly described as having "good water." But few of these wells are on the moraine. The deepest well noted by him along the line of the moraine is at Olive Green. This well, he reports, penetrated blue clay to a depth of 40 feet and obtained no water.[1]

Winchell has a list of 39 wells in Morrow County whose depth in drift ranges from 4 feet up to 50 feet.[2] Of these, 2 are chalybeate and 3 sulphurous, the remainder mainly "good water." From along the line of the moraine no wells exceeding 30 feet in depth are reported. He makes the statement[3] that gravel and sand are abundant in the eastern portion of the county, but that it is not usual to find these materials in the drift in the shale and slate area. This difference in structure noted by Winchell depends upon the morainic distribution rather than upon the underlying rock, there being sand and gravel in the main morainic system which occupies the eastern part of the county, but not in the moraine under discussion, which traverses its western portion. At the time this moraine was forming the conditions of deposition seem to have been such as to produce, as previously noted, a very small amount of sand and gravel compared with that found in the main morainic system.

[1] Geology of Ohio, Vol. II, p. 308. [2] Op. cit., p. 268. [3] Op. cit., p. 269.

BOWLDERS.

Surface bowlders are not conspicuous along the Powell moraine. On the whole they are no more numerous than on the intramorainic tracts, and are far less numerous than on the main moraine or on parts of the Mississinawa moraine in northeastern Indiana.

STRIÆ.

In the list of striæ given in connection with the description of the main morainic system those are included which were observed in the district traversed by the Powell moraine. They are in its eastern and southern portions. In the western portion of the Scioto Basin the drift is too thick to allow outcrops, but farther east outcrops occur and striæ are found. Whether these striæ date from the time the Powell moraine was forming or from an earlier time is not determined.

The following list includes those which lie in the Powell moraine or between it and the next later one. The first three are on sandstone, the remainder are on limestone:

Table of striæ.

	Bearing.
Iberia, 2 miles south of, in a quarry	S. 28° E.
Sunbury, 2 miles north of, on Walnut Creek	S. 45° E.
Sunbury, on Walnut Creek	S. 45° E.
Powell, west of, on Scioto River	S. 16° E.
Near Jerome, in quarry	S. 9° E.
Jerome, 2 miles north of, in Evan Piersol's quarry	S. 3° E.
Big Springs, on hill north of village	S. 8° W.
Big Springs, 1½ miles west of, in Musselman's quarry	S. 10° W.
Belle Center quarry, northwest of village	S. 10° W.

OUTER BORDER PHENOMENA.

Under this head are considered only those deposits which may be dependencies of the moraine, the other deposits having already been discussed.

Along Darby Creek considerable gravel and sand occurs, but this deposit is doubtfully classed as an outwash from the moraine, because it slopes toward the moraine instead of away from it. There is usually a descent in gravel plains in receding from the moraines which they border. But the slope of this plain is such that the stream flows near the north border of the gravelly tract next the moraine instead of at the southern border.

Along the Scioto and Olentangy rivers there are beds of cobble and gravel up to heights of 30 feet or more above the streams, which are apparently of glacial age, but as they occur north of this moraine as well as south the writer is inclined to connect them with a later moraine which crosses these streams near Delaware. On Alum Creek and Big Walnut deposits of gravel and cobble occur, but they have a feeble development compared with that along the Scioto and Olentangy. These streams are less favorably situated for carrying the waters from the later moraine, and this may account for the difference in the amount of gravel deposition. The moraine under discussion does not seem, on the whole, to have had so vigorous drainage as the next later one. On the interfluvial tracts all along the outer border of this moraine there is a narrow belt of land a mile or so in breadth characterized by very black soil. This seems to be the product of a swampy condition of the surface at some time, presumably at the time the ice sheet was melting.

INNER BORDER PHENOMENA.

No features of special importance were noted between this moraine and its neighbor on the north, the whole tract being a till plain with only an occasional low swell 5 to 10 feet in height.

WINCHELL'S INTERPRETATIONS.

In his discussion of the features of Union County N. H. Winchell recognized and called attention to this moraine, but he seems not to have noted its continuation in Delaware and Morrow counties. The features which are characteristic of the moraines of a continental ice sheet were so little known at the time his report was written (1874) that it does not seem singular that the moraine was not recognized by him throughout its entire length, but, instead, it is remarkable that the significance of certain portions of the moraine were so well understood. Concerning this moraine he says:[1]

> Between Big Darby and Mill creeks there is a very noticeable thickening of the drift. It rises into long ridges and high knolls which consist of hardpan or glacial drift. Northern bowlders and stones are on the surface and in the soil indiscriminately, though the same is true to some extent throughout the county. This ridge of drift is greatly developed at New California, where wells are sunk to the depth of 54 feet without meeting anything but "blue clay," the water being bitter. West and south of Marysville 2 or 3 miles the surface is high and rolling, with clay

[1] Geology of Ohio, Vol. II, 1874, p. 325, 331.

hills. Toward the north it is flat, with gravel near the surface in some places. Between Milford Center and Unionville "clay knobs" and rolling land can be seen north of Darby Creek, while toward the south and in Union Township the "Darby plains" extend several miles. Wells at Pottersburg penetrate the drift over 60 feet without meeting the rock, but obtain good water at that depth. About Newton there is a very rolling and bluffy tract of land, some of the wells obtaining bitter water in "blue clay" at 52 feet. This rolling strip of land dies out toward the south and west and toward the north and east. Throughout the rest of the county the surface is very nearly flat, wells being less than 25 feet. This belt of clay knobs crosses the entire county, though it seems to turn a little toward the north in Jerome Township. * * *

The drift ridge which separates Big Darby and Mill creeks has already been alluded to under the head of "Surface features." Its exact form, limits, and location, even within the county, have not been fully made out. The time given to the county would not allow a careful survey of this ridge in detail. It is well known to the inhabitants of the county. It forms a belt of high and rolling clay land which shows bowlders and gravel somewhat more abundantly than the surface of the rest of the county. It is believed to be of the nature of a glacial moraine, and was probably thrown down by the ice at a period when the retreating ice foot was nearly stationary for a long time at about that place. It is very similar to those other very extended drift remains that cross northwestern Ohio, but is somewhat more clayey than they. Its connection with them is not known, but it was doubtless contemporaneous in origin with one of them.

BROADWAY MORAINE.

This constitutes the second of the moraines of the Scioto lobe. It crosses the Scioto River above Columbus, and receives its name from a village in central Union County, which is situated on its northern slope.

DISTRIBUTION.

In Hardin and Logan counties this belt is combined with the Powell moraine, as shown in Pl. XIII. It becomes a distinct belt near the head of Mill Creek, a few miles west of Broadway, and passes slightly north of east to the Scioto River, crossing that stream immediately west of Delaware. East from this stream it is well defined for a few miles, but near the Olentangy River it loses strength, and there are two feeble belts which appear to form its continuation eastward. The outer one crosses the Olentangy a short distance above Delaware, and passing south of Eden, comes to Alum Creek at the bend east of that village, and then follows the north side of the stream to its source, near Mount Gilead, where it becomes merged with the Powell moraine. The inner member follows up the

northwest bluff of Whetstone Creek, and joins the Powell moraine just north of Mount Gilead.

The portion west of the Scioto is sharply outlined and has a breadth of about a mile. That east of the Scioto is less distinctly outlined and somewhat broader.

RANGE IN ALTITUDE.

The altitude near the Scioto and Olentangy rivers is about 900 feet, while on the borders of the Scioto Basin it is 1,150 feet or more. As in the Powell moraine, no rapid changes in altitude occur, but there is a gradual rise from the center to the borders of the basin.

RELIEF.

West of Broadway the moraine for several miles follows the north side of Mill Creek and stands 25 to 35 feet above the flood plain. Between Broadway and Marysville it leaves the creek and has a well-defined and rather abrupt outer border relief of about 20 feet. East of Marysville it follows the north side of Blues Creek for a few miles, and its relief is perhaps 20 feet, though it is difficult to determine on account of erosion along the valley. From Ostrander eastward to the Scioto the moraine for a few miles is not followed by a stream, and here it rises abruptly 20 feet or more above the plain south of it. Between the Scioto and Olentangy it is broken up into ridges and knolls which rise 12 to 20 feet above the nearly plane tracts south of them. Between the Olentangy River and Alum Creek, in the vicinity of the Big Four Railroad, the outer border relief is quite abrupt and is in places fully 20 feet. The railroad enters the moraine a mile or so south of Eden Station in a cutting 8 or 10 feet deep. Farther east, where the moraine follows Alum Creek the erosion has made it difficult to determine the relief.

In the inner member, which follows the northwest bluff of Whetstone Creek, the moraine is not a well-defined ridge, but consists of low "clay points" somewhat closely associated, that rise but a few feet above the bordering plains.

TOPOGRAPHY.

At the headwaters of the Scioto and Great Miami rivers in southwestern Hardin County, in the united belt, we find the morainic expression somewhat variable. Near Roundhead there are several sharp knolls 30 or

40 feet high, while immediately west is the Scioto Marsh, which over an area of several square miles is level as a floor. In other directions the greater part of the surface is nearly level, only low swells 10 to 15 feet high being present. Following the divide eastward few knolls exceeding 15 feet in height are found, but nearly all of the surface is gently undulatory. North of Silver Creek station the surface is rather elevated, standing about 100 feet above Silver Creek, which passes just east of it, and reaching probably 1,175 feet above tide. From the elevated part the descent is gradual in all directions. On this slope the morainic swells are low. At Taylor Creek, a tributary of the Scioto east of Silver Creek, is an esker ridge, and the moraine here swings abruptly southward, there being all along the west side of the esker morainic topography with numerous swells 10 to 15 feet in height, while east of it for several miles the surface is nearly level. At the south end of the esker the moraine contains a few gravel knolls 30 feet or more in height, but for some miles southward only low swells of till occur. In the tract southwest of the esker toward Belle Center, several basins were noted, a somewhat rare feature on this moraine. They vary in size from a fraction of an acre up to several acres each, and the centers are depressed several feet below the rims, their borders being in some cases abrupt, like the bank of a lake. They are still marshy and may once have contained lakes.

The moraine in its southward course from the Taylor Creek esker passes through Big Springs and West Mansfield. Its knolls are 8 or 10 feet high, and the relief above the outer border plain ranges from 10 to 40 feet; at West Mansfield it is about 35 feet. The Broadway moraine becomes distinct from the Powell near West Mansfield. From West Mansfield eastward it is usually characterized by low swells, seldom over 10 feet in height, but having a well-defined ridge as a basement for the knolls. South and southeast of Broadway the knolls are 10 to 15 feet or more high, and some of them are quite sharp. This topography continues to the Scioto River, though between Ostrander and the Scioto the crest of the ridge is smooth, while the slopes carry the usual swells. No morainic knolls were observed in the valley of the Scioto where this moraine crosses, but, as is shown later, a belt of gravelly knolls follows the border of the valley from Prospect southward nearly to the moraine, having a trend probably in line with the ice movement. On the east side of the river, west of Delaware,

the moraine carries knolls about 10 feet in height and also ridges with northeast-southwest trend rising 12 to 20 feet above the bordering plains.

On each member of the moraine, from the Olentangy eastward, swells are but 5 to 10 feet high, and rather scattering, so that the belts are somewhat less distinct than in the remainder of their course. Indeed the undulations are scarcely strong enough to merit the term morainic, though the belt can be distinguished from the plane tracts each side.

THICKNESS AND STRUCTURE OF DRIFT.

The general thickness of the drift in this belt, aside from the buried valleys, is 50 to 75 feet, but few borings showing greater depth than 75 feet to the rock. Where greater depth is found it is presumably at a filled-up valley; but the drift surface is so smooth and deep borings are so few that the courses and connections of preglacial valleys can not well be traced.

This moraine carries more gravel than the Powell moraine, yet it consists largely of till. Beginning at the northwest, the principal well sections obtained are described below.

About 3 miles west of Roundhead a well at a schoolhouse struck rock at 40 feet. Just north of the village of Roundhead James Dunlap has a well 164 feet deep which did not strike rock. It was mainly through blue till. Three miles north of Roundhead, on Mr. Street's farm, rock is struck at less than 90 feet. One mile northwest of Roundhead, at Daniel Simpson's, a well 140 feet deep struck no rock. There is said to be an outcrop of rock in the Scioto Marsh, about 4 miles northwest of Roundhead, though several flowing wells on the marsh at about the same level struck rock at 80 to 90 feet. About 4 miles northeast of Roundhead, at a schoolhouse, rock was struck at 80 feet. At Samuel Collins's, near the south end of the Taylor Creek esker, 2 wells 35 feet deep are mainly through blue till, and struck no rock.

At Belle Center much variation in the altitude of the rock surface is found. There is a quarry in the northeast part of the village at a somewhat higher level than the railroad station. Two gas wells in the village penetrate in one instance 44 feet, and in another 160 feet of drift. The greater part of the drift in the gas wells is till. Several flowing wells at Belle Center have a depth of 18 to 25 feet. They penetrate about 10 feet

of yellow till, then a few feet of sand, then a "hardpan crust," beneath which there is water-bearing gravel. At Big Springs a rock outcrop just north of the village stands considerably above the railway station, while in the vicinity of the station wells have struck rock at 12 to 38 feet.

At West Mansfield the town well struck rock at about 100 feet. It is mainly through blue till. Several other wells near West Mansfield have a depth of 50 to 60 feet, and none reached rock. The general thickness of the drift here is thought to be about 100 feet.

On the moraine about a mile southwest of Broadway a well on a farm formerly owned by Frank Welch is reported by him to have struck rock at 65 feet.

At James Rodgers, on the crest of the moraine between Ostrander and Scioto River, a well struck rock at about 50 feet. There is yellow till 10 or 12 feet, below which is blue till extending to the rock.

Where the moraine crosses the Scioto Valley till is exposed near the water's edge, but above it is a terrace capped with gravel. The bed of the river here is on rock. The valley is fully 100 feet below the level of the highest points in the moraine on each side.

In Delaware there are outcrops of rock near the Hocking Valley Railroad station at a level but 12 to 15 feet below it, or 915 feet above tide. The drift surface northwest from this quarry, on the moraine, reaches an altitude about 30 feet above the station, and it is probable that the difference in altitude is due entirely to drift accumulation, though no borings have been made to furnish complete evidence.

From Delaware northeastward the drift has a thickness usually of but 20 to 30 feet. The morainic tracts are known as "clay land," and the bordering plains "black ground," since there is but little black soil on the moraines compared with that on the bordering plains.

BOWLDERS.

The number of bowlders is somewhat greater on this moraine than on the bordering plains, but only one locality was noted where they are so numerous as to be troublesome. This is in southern Hardin County, on the east side of Silver Creek, about 3 miles from Kenton. Here, on the farm of J. Y. Ross, there are several hundred within a space of 10 acres. They are, so far as observed, all of Canadian derivation. Winchell noted

a large bowlder in Alum Creek bottoms, near South Woodbury, "the extreme dimensions of which are 9 feet by 7½ feet, showing 4½ feet above the ground. In this bowlder hornblende predominates, and the feldspar is flesh-colored, quartz being scarce, giving a rather dark color to the whole.' The bowlders are usually much smaller than the one noted by Winchell, the majority falling below 3 feet in greatest diameter.

STRIÆ.

The striæ observed in this district, so far as the moraine is distinct from the others, are confined to a single occurrence, the one in the west part of Delaware where the bearing is S. 8° E. It appears in the list of striæ given in the discussion of the main morainic system.

OUTER BORDER PHENOMENA.

The ice sheet apparently had at the time the Broadway moraine was forming two main lines of escape for its waters, the Scioto and the Olentangy valleys. Of these the Olentangy seems to have been the larger. There are beds of gravel and cobble at Delaware near the outer border of the moraine which show vigorous drainage, while west of Delaware on the Scioto there is a terrace cut in the till that filled the valley, but the terrace is capped with a finer gravel than that on the Olentangy. In each valley the bed of the glacial stream seems to have been 20 feet or more above the present stream. The breadth of the terrace on the Olentangy is nearly one-half mile, while that on the Scioto is less than one-fourth of a mile.

North from Marysville, where the moraine crosses the tract lying between Mill Creek and Blues Creek, it is bordered on the south by a gravel plain, which is said to follow it eastward to Ostrander, but it was examined only near the Union County Infirmary, north of Marysville. It consists of a plain one-half mile or less in width, slightly lower than the till tract south of it, and 20 to 30 feet or more below the moraine north of it. It is underlain by gravel but has a rich, black, mucky soil. An occasional low mound of gravel dots its surface. Its altitude by barometer is only 10 feet above the bridge on Mill Creek at Marysville, and it is probably less than 20 feet above the creek at its nearest approach immediately west of the Infirmary. Since this low gravel plain forms a direct connection between the upper and lower portions of Mill Creek, it may possibly be

simply an old course of the creek. The presence of the gravelly knolls seems to oppose this idea and to show that the gravel tract was not occupied by a stream after the ice had withdrawn, though it may have been the course of the creek previous to the formation of the Broadway moraine. It is thought that the ice sheet may have projected slightly beyond the main ridge of the moraine and formed these knolls on the plain.

Along Mill Creek there is not a conspicuous amount of gravel and sand; on the contrary, its bluffs are usually composed of till and, with the exception of a stretch embracing a few miles near its mouth, they stand but a few feet above the flood plain of the stream. Near the mouth of the creek at the crossing of the New California and Delaware roads, there are rocky bluffs rising to a height of 50 feet above its bed, and the valley is very narrow, scarcely 100 yards in width. Above the bluff of rock there is a thin capping of drift, mainly clay, which does not show clear evidence of fluvial action.

Alum Creek, another stream leading southward from the outer border of the moraine, is characterized for some miles below the moraine by a narrow valley bordered by high bluffs of shale rising 80 feet or more above the stream. Wherever the valley was crossed the shale is capped by till. If there had been a discharge of glacial waters down the valley the stream would apparently have been confined between the rocky bluffs of its present narrow valley, which is even now occupied in places throughout nearly its whole breadth by the creek.

Aside from the fluvial phenomena noted, the outer border district consists of a till plain, in which the number of "clay points" is fewer and the proportion of "black ground" much greater than on the moraine.

INNER BORDER PHENOMENA.

There is, north of the Broadway moraine, an extensive district in which the drift is comparatively thin (15 to 30 feet in general depth) and is composed mainly of till. The surface is nearly all plane, and bowlders are less conspicuous than on the moraine, but are not rare. Along Bokes Creek, a western tributary of the Scioto flowing nearly parallel with the moraine and less than 10 miles distant from it, there are in places slightly undulatory tracts suggesting the marks of an ice margin, but there does not appear to be a well-defined moraine. The valley of this creek is of interest,

inasmuch as flowing wells have been obtained along it throughout almost the entire length of the stream. The flow of water is from gravel below blue till. The depth of the wells seldom exceeds 30 feet, and the water rises but a few feet above the surface. The wells are all, so far as noted, on the flood plain of the stream.

TAYLOR CREEK ESKER.

The features of greatest interest in this district are the eskers and other beds of assorted material that show the work of water in connection with the ice sheet. The Taylor Creek esker has already been referred to, and the other belts have been well described by N. H. Winchell in his report on the geology of Ohio. The Taylor Creek esker, being the best illustration of that class of formations found in this district, first receives attention. It lies in Hardin County, nearly due south from Kenton, as indicated in Pl. XIII, its north end being about 3 miles from that city. By the residents it is known as the "Devils Backbone," and less commonly as the "Taylor Creek Ridge." Its length is about 3 miles. The most prominent part has a trend nearly north to south, but local variations occur, as described below. It so nearly coincides in trend with the bearing of neighboring striæ at Big Springs and Belle Center (S. 10° W.) that it represents the direction of the ice movement about as well as the striæ, and yet its local variations seem to be out of harmony with the direction of the ice movement, it being scarcely probable that the great ice sheet made the sudden deflections which this ridge exhibits

For nearly a mile in its northern portion the ridge is low, seldom exceeding 10 feet in height, and is subject to frequent gaps and to sudden changes in trend. It then rises to a height of 20 to 30 feet or more, and for perhaps one-half mile exhibits considerable winding and is interrupted by short gaps. Here the main ridge sets in and is nearly continuous for about 1½ miles, lying in Taylor Creek Valley on the west side of the stream. Its height is 30 to 50 feet and the breadth at top sufficient for a wagon road. The slopes are, as a rule, very sharp, being 30° or even greater from the horizontal. At the southern end of this main ridge a low ridge slightly separated from it leads off toward the southwest a few rods and there dies away. About one-fourth mile to the south a sharp gravel ridge with northwest-to-southeast trend appears and runs from the center of the valley up to the east bluff of the creek, a distance of about one-fourth of a

mile, where it dies out. Nearly one-half mile farther south sharp gravelly knolls appear in the valley. They seem to constitute the southern end of this system of ridges, for toward the west, south, and east there is a till tract. The disjointed northern portion of the ridge is not in the valley of Taylor Creek, but crosses the uplands on the west side of the stream and makes a descent of about 50 feet in entering the valley.

There is not a well-defined esker trough on the uplands, but the lowland tract in which the esker mainly lies, and which is now called Taylor Creek Valley, is to all appearances an esker trough, and was probably excavated by the stream which deposited the esker. Its breadth is 200 to 300 yards, and in but few places is its depth less than 30 feet. The uplands east are lower than those west of it. The stream occupying it is hardly worthy the name creek, its bed being scarcely 10 feet in width where it borders the esker. The small size of the stream no less than the presence of the esker opposes the idea that this valley was formed by the present stream after the ice sheet had withdrawn.

Many excavations have been made in the disjointed portions of this esker, but none of great extent in the main ridge. The main ridge, however, has been examined sufficiently by persons negotiating for the sale of the ridge to railway companies to make certain that its great mass consists of gravel of suitable coarseness for railway ballast. Its structure is probably more uniformly gravelly than that of the disjointed ridges. Indeed, the disjointed ridges have proved to be extremely variable in structure, containing not only gravel and cobble, but fine sand and till and gradations from till into assorted material. The latest deposit on these disjointed ridges seems to have been till, for till is in several places exposed on the slopes where the interior consists of well-assorted material. Till also occurs sometimes on the inner curve of a ridge where the outer curve consists of a well-washed gravel. At the disconnected ridge south of the main ridge, noted above, there is coarse gravel at the northwest end in beds dipping toward the southeast, which traced southeastward becomes finer and terminates at the southeast end in a sandy till. The bedding, both by dip of beds and the attitude of individual stones, shows clearly that the flow of water was northwest to southeast—that is, from the coarse gravel toward the sandy till. This ridge represents, therefore, a deposit in a stream whose flow was being rapidly checked. We find in this sudden change in the

degree of assorting and force of current, and also in the existence of an excavated trough, strong evidence in support of the hypothesis of the subglacial origin of the esker. By this it must not be understood that all eskers are thought to have been formed in subglacial channels; indeed, it seems not improbable that in some instances they may have had a superglacial origin, having apparently been formed in a channel open above to the air. Possibly cases occur in which an esker is in part superglacial and in part subglacial in its origin, the stream which formed it being for a portion of its course on the surface or in a deeply covered tunnel or chasm in the ice, while later, or upon approaching the ice margin, it flowed on the ground beneath the ice and excavated the trough. In places where the current was not swift enough to carry onward all the material it deposited the material for the ridges. In some esker systems a delta or fan was developed at the end nearest the margin of the ice sheet, but in the Taylor Creek esker no such delta appears. The tracts where the esker terminates, as well as those bordering it, are underlain by till, and show no more assorted material than portions of the moraine not associated with an esker.

RICHWOOD ESKER.

In the village of Richwood, in Union County, there is a low gravel ridge of the esker type. It is 10 to 15 feet high where most prominent, and 30 to 50 yards wide. It sets in about one-half mile north of Richwood station, and runs in a course S. 20° E. to the business portion of the village. From Richwood southward no well-defined ridge appears, but a nearly plane gravelly belt in line with the ridge continues to Fulton Creek, 1½ miles south of the village. The bordering tracts are till. The relation between this level gravelly belt and the esker is thought to be somewhat close, both being deposited probably by a glacial stream, the esker perhaps in a narrow tunnel and the level-surfaced gravel in a broad one. The thickness of drift in Richwood along the line of this gravelly belt is only about 30 feet.

RADNOR ESKER.

A gravelly belt formed along the Scioto River Valley from Prospect southward to the moraine has been well described by Winchell, as follows:[1]

> A singular line of gravel knolls and short ridges pertaining to the glacier drift crosses Radnor Township, coming into the county from the north at Middletown

[1] Geology of Ohio, Vol. II, 1874, pp. 304-306.

[Prospect], which is on the Scioto, in Marion County, and passing about a mile to the west of Delhi. It is traceable nearly to Millville. It is intersected by the gravel road about a mile north of Delhi. The road then follows it to Middletown, where it becomes lost from further observation. This interesting series of ridges is not arranged in a single continuous line, but the separate ridges overlap each other, rising and falling at irregular intervals. Sometimes the line appears double; low places on one side are in some places made up by full deposits on the other. On either side the country is flat, the soil is of close clay, and the roads very muddy in rainy weather. The Delhi beds of the Lower Corniferous are exposed at a number of places in close proximity to these gravel knolls, proving the strike of the formation to be exactly coincident with this strip of gravelly land. Toward the east is the enduring Corniferous; toward the west, the easily disrupted Waterlime. There is a general but very gentle slope to the west. The material in these ridges is stratified sand and gravel, which has been considerably used in constructing the gravel roads that intersect that part of the county. One of these sand and gravel deposits is open for such purposes on the land of Mrs. Rachael Fleming, on the east side of the Scioto, near the mouth of Bogg's Creek, and shows the following alternation of parts: (1) Soil and hard pan, 2 feet; (2) gravel and sand, stratification confused or wanting; (3) handsome strata of sand obliquely stratified.

The outward appearance and composition of this series of gravel ridges are the same as of those ridges well known in the country as "hogs'-backs," yet they are less prominent than some others that have been described in northwestern Ohio. (See report on the geology of Hardin County, also report on geology of Allen County.) Their long continuance and their more uniform height make them in some respects comparable to those very long gravel ridges that have been described in northwestern Ohio, and referred to the effect of glaciers, crossing a number of counties consecutively. Their real origin, however, is not that of terminal glacier moraines, but is the same as of those isolated gravel knolls known as "hogs'-backs." Similar lines of gravelly rolling land following and marking the boundary between two geological formations have been mentioned in reports on the geology of Crawford and Morrow counties. Such boundary lines, when between two formations of unequal endurance under the glacier, would be the place where most frequently deep fissures in the ice would be produced by the efforts of the great sheet to adapt itself to the unevenness of its bed. In such fissures and along such openings running water would appear, and would most effectually carry away the transportable clayey portions of the drift with which it might come in contact. During the prevalence of the ice, such washed and perhaps stratified drift would be liable to a further transportation; but when the margin of the glacier finally passed northward over any point on such boundary line, the final effect of the water issuing from the ice at that point would be left undisturbed, and would be preserved to the present time. The obliqueness of the stratification and the sudden changes in the kind and arrangement of material making up the strata, together with an occasional mass of unassorted glacier clay included in the stratified portions, not only indicate the force and direction of the torrents of water and an interrupted supply of drift, but also the presence and agency of thick glacier ice at the time of deposition.

LEESVILLE ESKER.

A short esker near Leesville, in Crawford County, about 3 miles west of Crestline, is also described by Winchell in his report on that county, as follows:[1]

At Leesville, in the southern part of section 7, Jackson, is a long and prominent ridge of gravel popularly denominated a "hog's-back." The gravel ridge has been in use for fourteen years, during which time thousands of carloads have been taken away for the Pittsburg, Fort Wayne and Chicago Railroad, but the part which still remains rises 40 feet above the surrounding level. A former spur from this, known as the "Cleveland Hill," rose 20 feet higher, but it has been entirely removed. This gravel ridge is a little over half a mile long and runs nearly north and south, or a trifle east of south. The "Cleveland Hill" tended more easterly along the southern extremity. The main ridge lies on the observed line of superposition of the Berea grit over the Bedford shale. The soft shale is in outcrop along the banks of the Sandusky River, on section 12, within a quarter of a mile of the ridge, and the sandstone is extensively wrought about half a mile east of the ridge. This ridge is not bordered on both sides by low, swampy belts, as several others have been observed to be, at least it is not on the eastern side. On the west side there is more low ground, but the Sandusky River and a ravine tributary to it have somewhat broken up its original surroundings in this respect. The country about is flat, or nearly so, and the drift is made up of the common hardpan clay. The gravel of the ridge embraces a great many bowlders about the size of 18 inches in diameter: some also much larger. This conjunction of a gravel ridge pertaining to the drift with the line of outcrop of two formations, the one hard and the other soft, is not an uncommon occurrence in northwestern Ohio. They are mentioned under the head of "Drift" in the reports on Auglaize, Hardin, Allen, Morrow, and Delaware counties, and seem to the writer to bear an intimate relation to the cause of that deposit. They indicate that whatever that cause was it was susceptible of being influenced by the character of the underlying rock.[1]

The coincidence between the line of strike in the rock formations and trend of the esker noted by Winchell is not to be found in all eskers. While, therefore, it is not always necessary that there should be a line of outcrop of two formations, one hard and the other soft, to cause the deposition of an esker, it still may be true that the position of the stream which produced the esker was determined by the resistance offered by the hard strata to the flow of the ice sheet as suggested by Winchell.

CORRELATIONS.

This moraine appears to be the equivalent of Winchell's St. Johns moraine of the Maumee-Miami glacier, which when traced into Indiana is called the Salamonie moraine.

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[1] Geology of Ohio, Vol. II, p. 247.

In the shoulder east of the main Scioto lobe no well-defined morainic belts occur which can be correlated with the Broadway moraine, but, as stated in the discussion of the Powell moraine, there are occasional developments of morainic topography in that district between the main system and a later system following nearly the Mississippi-St. Lawrence divide. These fragmentary moraines are probably correlatives of the well-defined moraines in the northern part of the Scioto Basin. The ruggedness of the district within the shoulder may have prevented the formation of continuous belts.

MOUNT VICTORY MORAINE.

This is the northernmost of the moraines that are crossed by the Scioto above Columbus. It is well developed from Mount Victory in southeastern Hardin County eastward to the meridian of Marion, a distance of about 20 miles. It may also be traced for 2 or 3 miles northwest from Mount Victory. This brings it nearly to the Scioto River, where it becomes merged with the later, stronger, Wabash moraine. Eastward from Marion there seems to be no continuation of this moraine, for a comparatively flat tract extends for several miles in that direction. Along the headwaters of the Olentangy, however, there are drift knolls, which in places are so closely aggregated as to give the appearance of a moraine, and it seems probable that the continuation of the ice margin at this time of halting was along that line. For some reason not yet determined, the southeast limb of all the moraines crossing the Scioto Basin above Columbus is much weaker than the remainder of the belts. In the Powell moraine the southeast limb, though very narrow compared with its breadth elsewhere, is sufficiently strong to leave no doubt as to its course, but in the Broadway moraine it is only by close comparison with the bordering tracts that one can decide upon the course of the belt. In the Mount Victory moraine this limb is practically wanting for several miles, so that no clew to its course was found; the belt is well defined only at intervals along the Olentangy.

Where well defined the Mount Victory moraine has a breadth of 1 to 2 miles. It does not rise much above the plain south of it, though for several miles it determines the eastward course of Rush Creek, and at the Scioto, on each side of the stream, it has an abrupt outer border relief of 25 feet or more. Between the Scioto and Rush Creek the inner (northern) border is more abrupt than the outer and the descent from the moraine northward to the river is more rapid than it is southward.

The morainic knolls seldom exceed 15 feet and the majority fall below 10 feet in height, but this amount of undulation puts the moraine in striking contrast with the very level tracts bordering it, on which an undulation of 5 feet can scarcely be found. The moraine differs from the bordering tracts also in being much more liberally supplied with surface bowlders. Winchell, in his report on Marion County, calls attention to these bowlders, some of which are stated to be 6 feet in diameter.[1] The bowldery tract referred to by Winchell is immediately west of the Scioto River, where the bowlders are perhaps more numerous than in any other part of the moraine.

The moraine, like the bordering plains, seems to be composed mainly of till. Two wells in Mount Victory reach the rock at about 60 feet. One is at a livery stable, the other is the town well in the street southeast of the station of the Big Four Railway. In each the drift is mainly till. The southern part of the city of Marion touches the inner border of the moraine. Here wells in the vicinity of Delaware avenue, at a level about 20 feet above the railway stations at Marion, penetrate 50 feet of drift, mainly till. In the business portion of the city of Marion and from there northward to the quarries, a mile north of the city, there is scarcely any drift, so that rock is struck in many places in grading the streets.

That there was not a vigorous drainage down the Scioto at the time this moraine was forming is inferred from the character of the valley drift. No well-defined terrace heads in the moraine, and the valley is filled with till from the moraine southward to Prospect, as it is from the moraine northward. On a previous page Winchell's account of a gravelly belt along the Scioto from Prospect southward is presented. This gravelly belt, however, was apparently a subglacial formation about contemporaneous with the Broadway moraine. It certainly has not the level surface of a terrace.

Between this moraine and its neighbor on the north there is a plain, much of which is treeless. It has a black prairie soil a foot or more in depth and occasional low knolls rise abruptly above the level of the plain. These have a clayey soil less black than the plains. The drift on this plain ranges from a thin coating up to 50 feet or more in thickness and is mainly till. Occasional bowlders dot the surface, but they are not so numerous as on the moraine south of the plain.

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[1] Geology of Ohio, Vol. I, 1873, p. 644.

The cause of this extensive prairie tract in the midst of the forests of Ohio is an interesting problem, but a solution has not yet been found. It is popularly supposed that these treeless plains were once covered by a lake; but they have not the horizontal surface which a lake bottom should have. Instead the surface rises from west to east at the rate of 10 feet or more per mile, the altitude near the Scioto being 920 feet, while on the eastern borders of the prairie, 12 to 15 miles eastward, it is fully 1,050 feet. The prairie extends north beyond the plain, occupying a portion of the moraine that follows the divide between the Scioto and Sandusky rivers. Its altitude decreases toward the north, until near Upper Sandusky it is but 850 feet. No well-defined lacustrine formations, such as beaches or sand deposits, were observed on its surface. The soil has fewer pebbles than ordinarily characterizes the till plains, but it is not a pebbleless clay. It seems to be a glacial deposit, and the presence of surface bowlders of Archean rocks makes it evident that not much deposition has occurred since the ice sheet withdrew, else they would have been covered.

SECTION III. MORAINES OF THE MAUMEE LOBE.

WABASH MORAINE.

The portion of this moraine traversing western Ohio was traced some years ago by N. H. Winchell, and by him was given the name Wabash[1] More recently Dryer has traced much of the portion in Indiana.[2] The writer's observations cover the interval between the portions thus studied, and also extend the entire length of the moraine in these States.

DISTRIBUTION.

The Wabash moraine does not connect with the interlobate morainic tract of Logan and southern Hardin counties, Ohio, but, as indicated in Pls. XI and XIII, may be readily traced from the highlands east of the Scioto Basin westward across that basin into the region occupied by the Maumee-Miami lobe. Farther east it is closely associated with a later moraine (the Fort Wayne). The combined belt, however, is traceable eastward into an interlobate moraine occupying the highlands west of the Grand River Basin, beyond which it has not been recognized.

[1] Proc. Am. Assoc. Adv. Sci., 1872, pp. 166–167.

[2] Sixteenth Ann. Rept. Geol. Survey Indiana, 1888, pp. 119–122.

From the interlobate moraine just referred to, the combined Wabash and Fort Wayne moraine takes a westward course along the continental divide, constituting that divide from near Akron to the head of Huron River, about 15 miles northwest of Mansfield. For a few miles between the villages of Creston and Savannah the two moraines are distinct, but with this exception they are combined into a single belt as far west as the point named. Farther west the two belts are more widely separated, and only the Wabash will now be traced.

The Wabash moraine follows the north side of the westward-flowing headwater portion of the Sandusky River to the village of Wyandot, where the river turns northwestward through the moraine. The course of the moraine is there southward for a few miles along the west side of Little Scioto to Scioto River at the bend of that stream west of Marion. The moraine then follows the north side of the headwater portion of the Scioto to the Scioto Marsh a few miles west of Kenton, Ohio. From this marsh its course is south of west along the north side of the Auglaize River to Wapakoneta. The river here turns northward, passing through the moraine, while the latter continues westward to the town of St. Marys, and thence along the north side of the Grand Reservoir and Big Beaver Creek to the bend of the Wabash River, near the State line, where it assumes a similar position with reference to that stream. For 30 miles or more in eastern Indiana it trends north of west, and lies immediately north of the Wabash, but near Bluffton the river takes a nearly westward course and leaves the moraine. The latter continues in a course north of west past Zanesville to the old lake outlet at Aboit, in western Allen County. This outlet crosses at the most westerly point of the morainic loop. North of the outlet the moraine takes a northeasterly course, its inner border following the lake outlet nearly to Fort Wayne and the St. Joseph River north of that city, while the outer follows the east side of Aboit River and the Huntertown marshes to northern Allen County. It there crosses Big Cedar Creek, and follows its east side to the vicinity of Auburn. The moraine here swings eastward, and enters Ohio southeast of Butler, Ind. In northwestern Ohio it follows the west side of the St. Joseph River to the Michigan line. Its exact course and its connections in Michigan are not determined.

Like the Mississinawa and Salamonie moraines, this belt governs to a considerable degree the course of the streams that drain it. By reference

to the map (Pl. XI) it will be seen that streams in northwestern Ohio and northeastern Indiana usually flow either parallel with or at right angles to the trend of the moraines. In both cases the course plainly results from slopes due to drift aggregation. This is true of the Mississinawa, the Salamonie, the Wabash, the St. Marys, the St. Joseph, and the Auglaize rivers, as well as of several smaller streams. Attention is here called only to such as have their courses controlled by the Wabash moraine. The westward-flowing portion of Sandusky River, the eastward-flowing portion of the Scioto, and the westward-flowing portion of the headwaters of Auglaize and St. Marys rivers and Big Beaver Creek are all controlled by this moraine. The Wabash above Fort Recovery has its course governed by the Salamonie moraine; the river then flows northward for several miles as if to discharge into the Maumee River, but upon reaching the outer border of the Wabash moraine it is turned westward, and instead of flowing into the Maumee and becoming a part of the St. Lawrence drainage basin, it passes westward to the old lake outlet at Huntington, and eventually discharges into the Gulf of Mexico. Had a suitable break occurred in the Wabash moraine, either in western Ohio or eastern Indiana, the upper portion of this stream might have become a part of the St. Lawrence system.

Blue Creek, in Adams County, Ind., after flowing for several miles parallel with the inner border of the moraine, and distant but 4 or 5 miles from the Wabash River, turns abruptly northeastward and discharges into the St. Marys River.

In Wells County, Ind., two small streams flow along the inner border in opposite directions, but parallel with the moraine, when they find a break which permits their passage through it into the Wabash near Bluffton. The bends in Eightmile Creek, in Wells County, between Ossian and Zanesville, are also determined by the morainic ridges.

The southwestward course of Big Cedar Creek, in Dekalb County, from near Auburn to northern Allen County, is due to the presence of the moraine. The creek then flows in a southeastward course, or almost exactly at a right angle to the course above this bend.

RELIEF.

The Wabash moraine throughout much of its course presents an abrupt, bluff-like outer border relief of about 30 feet, but the relief ranges from 20 feet or less up to 50 or 60 feet. After the moraine bears away from the Wabash River, in northern Wells and western Allen counties, the relief above the outer border plain is usually but 20 to 25 feet and occasionally but 10 to 15 feet above this plain. North of the old lake outlet the crest of the moraine stands 20 to 50 feet above the valley-like plain which occupies much of the outer border. The slope is, however, so broad that the relief is not so striking a feature as in the southern portion of the loop, except locally. Near Hunterstown, for example, there is a rather abrupt rise of about 20 feet from the marshes into the border of the moraine.

On the inner border there is a gradual descent from the moraine to the streams which follow the outer border of the Fort Wayne moraine, viz, Brokensword Creek, Hog Creek, St. Marys River, and St. Joseph River. In a few places the moraine rises abruptly 20 feet or more above the adjacent portion of the inner border plain; quite as often, however, there is no abrupt rise but a gradual transition from the plain to the moraine.

RANGE IN ALTITUDE.

The range in altitude in the Indiana portion of this moraine is very slight, the highest points being scarcely 900 feet above tide, while the lowest points (aside from valleys of streams) are about 850 feet. In Ohio there is a gradual ascent from about 850 feet at the Miami Canal to 1,025 feet at the north border of the Scioto Marsh in Hardin County. The moraine then drops to about 925 feet at the bend of the Scioto west of Marion, but rises to 1,050 feet at its junction with the Fort Wayne moraine near the head of Sandusky River. The combined belt eastward from there to Akron ranges from about 970 feet in lowlands to 1,250 feet on ridges.

The old lake outlet at Aboit, Ind., is about 750 feet above tide, or nearly 100 feet below the altitude of the crest of the moraine through which it has a passage.

The following altitudes of points along the crest of the moraine will serve to illustrate the above remarks:

Table of altitudes along the Wabash moraine.

Station.	Authority.	Altitude above tide.
		Feet.
Creston	Wheeling and Lake Erie R. R	970
Burbank, south of	Barometric	1,200
Killbuck Valley, east of Congress	Barometric	900
Congress, ridge 1½ miles west of	Barometric	1,215
Lake Fork, south of West Salem	Barometric	1,025
Polk station	Erie R. R	1,240
Jerome Creek, north of Ashland	Barometric	1,040
Shiloh, high point 6 miles east of	Barometric	1,200
Shiloh	Big Four R. R	1,080
Bucyrus, northwest of	Barometric	960
Agosta	Big Four R. R	941
Larue	Big Four R. R	926
Kenton, meteorological station	Ohio Meteorological Bureau	1,050
Scioto Marsh, near	Barometric	1,020
Scioto Marsh, crest north of	Estimated	1,025
South of Westminster, Ohio	Estimated	1,000
Wapakoneta, 2 miles north of	Cincinnati, Hamilton and Dayton R. R	923
St. Marys, in valley	Estimated	850
St. Marys, on ridge	Estimated	890
Crest near Celina	Estimated	910
Near Berne, Ind	Grand Rapids and Indiana R. R	865
East of Bluffton, Ind	Toledo, St. Louis and Kansas City R. R	867
Near Kingsland	Chicago and Erie R. R	878
Bowman's, sec. 8, T. 29, R. 11, E	C. R. Dryer	873
Upland south of Aboit	Prel. Surv. Wabash R. R	848
Aboit station	Wabash R. R	753
Summit east of Aboit River	New York, Chicago and St. Louis R. R	865
Summit near Hadley	Pittsburg, Fort Wayne and Chicago R. R	853
Summit north of Wallen	Grand Rapids and Indiana R. R	887
Dutch Ridge, in Allen County	C. R. Dryer	923
Summit east of Auburn	C. R. Dryer	900

TOPOGRAPHY.

In general it may be said that the narrowest portions of the moraine are also the most prominent. In Ohio and throughout the greater part of the portion south of the old lake outlet, the moraine is crowded into a space about 1 mile in width, and consequently presents a definite ridge. North from the outlet it is spread over a width of 3 or 4 miles, and is correspondingly inconspicuous, though it contains morainic features of characteristic type.

In the Ohio portion of the moraine as far east as the uplands east of the Scioto Basin, there is little variety in feature. The moraine is most conspicuous by its relief, standing as it does 20 to 40 feet or more above the outer border plain. Its surface carries only low swells, seldom 20 feet and usually but 5 to 10 feet in height. In places the crest lies within one-fourth mile, but usually it is about one-half mile distant from the outer border. The inner slope is longer than the outer, as is the case in nearly all the moraines of the smooth ridge type in Ohio and Indiana.

On the uplands west of the Cuyahoga the morainic features are well displayed. The district is hilly, but the borders of the morainic belt are easily recognized. In the districts to the north and to the south the valleys have only occasional drift knolls, while the slopes of the ridges are nearly free from them, but within the morainic belt the valleys are filled with these knolls, while the slopes and crests of the ridges are dotted by them, there being scarcely a 40-acre field on which there are not one or more knolls to be seen. On its outer (southern) border a nearly continuous sheet of drift 20 feet or more in thickness is present, into which an abrupt rise is made from the outer border district. This sheet of drift is dotted by drift knolls 5 to 50 feet in height. The most conspicuous ones noted are north of Smith Roads, where they are associated in groups whose height ranges from 20 to 50 feet, but the general height of these knolls is 10 to 15 feet and their area 2 to 5 acres. South of Smith Roads the drift shows a tendency to aggregation in ridges trending ENE. to WSW., the general trend of the moraine being nearly east to west. West of the meridian of Sharon the ridges trend NNE. to SSW., near the outer border of the complex morainic belt, while near the inner border, in the vicinity of Remsons Corners, they trend nearly north and south. The tendency to

distinct ridging is more pronounced on the west than on the east side of the Cuyahoga.

Upon approaching the valley in which Rocky River and the River Styx find a common source, the belt of morainic drift assumes a more subdued expression, its knolls being seldom more than 10 feet in height. The change in topography coincides with a change in structure, the drift being a compact till in the vicinity of Rocky River, while east of that stream it contains much assorted material and its till is quite porous.

The Wabash moraine is feebly developed on the uplands west of the valley in which Rocky River and the River Styx have their sources, consisting only of low swells 10 to 15 feet or less in height, which are less closely aggregated than in the corresponding portion of the Fort Wayne moraine. In the Chippewa Valley it is also feeble, the knolls being very few and separated by extensive marshy tracts. Similar marshy tracts occupy the low divide between Chippewa and Killbuck creeks. After crossing the headwaters of Killbuck Creek, near Creston, the moraine rises to the uplands and assumes considerable strength, there being sharp knolls 25 to 40 feet in height. There are also ridges whose general trend is ENE. to WSW., but which are connected occasionally by cross ridges. The inclosed low tracts contain small knolls. Upon approaching the southward-flowing portion of Killbuck Creek, near Congress, the moraine consists of a single ridge about one-half mile in width, standing 25 to 30 feet above the plain on its outer (southern) border. Its crest and slopes have undulations of 10 to 15 feet and there are a few basins along the crest, the deepest of which are depressed 6 to 8 feet. For a mile or more north of this main ridge there are occasional swells 8 to 15 feet in height, but the greater part of the surface is smooth.

No trace of the moraine was found in Killbuck Valley east of Congress, but it reappears on the west bluff and passes just north of that village. It there consists of short ridges 10 to 20 feet in height with east-west trend, and knolls of similar height. The moraine enters Lake Fork Valley just above Pleasant Home, and has a well-defined terrace connected with it in which are numerous shallow basins, such as frequently characterize outwash aprons and the heads of moraine-headed terraces. On a western tributary of Lake Fork, in eastern Ashtabula County, west from this place, there is also a moraine-headed terrace. The road from Pleasant Home to

Ashland leads across the valley near the head of the terrace, there being an open valley south of the road with a terrace standing about 25 feet above the stream, while toward the north the valley and its slopes are dotted with drift knolls and ridges 10 to 20 feet in height.

On the uplands between this tributary of Lake Fork and Jerome Fork the moraine has rather feeble expression, its knolls and ridges being but 10 to 15 feet high. It stands, however, nearly 20 feet above the tract south of it.

In the valley of Jerome Fork, north of Ashland, it is well developed, with numerous basins, and with knolls often 15 to 25 feet in height.

West of Jerome Fork the moraine enters a less hilly district than that to the east. The preglacial valleys and ridges are either entirely obscured or are represented only by broad sags and low divides whose slopes are scarcely appreciable to the eye. The moraine is, therefore, a more conspicuous feature than in the hilly districts, though it has little, if any, stronger expression. Its knolls and ridges commonly fall between 10 and 25 feet in height, and basins are not numerous, but there is a nearly continuous main ridge with well-defined crest, which stands 15 to 30 feet or more above the outer border district.

The knolls are somewhat sharper and higher on the eastern and western borders of the Scioto-Sandusky Basin than in the central portion, their height in the central portion being usually but 5 to 10 feet. The central portion was a prairie region when the country was settled, while the borders were heavily timbered. Whether the softening of contour in the prairie district is due to a more rapid subaerial erosion there than in the timbered districts, or to original differences in features occasioned by the ice sheet, has not been determined. Neither is it apparent why this district was untimbered, for, as in the great prairies of Illinois and other western States, timber flourishes wherever introduced by the residents.

This prairie tract differs from the level and marshy prairies which appear on portions of the continental divide in Ohio in being dry land and in having an inclined surface whose altitude has a range of fully 150 feet. It is not probable, therefore, that it is an old lake bottom, as has been supposed by many of the residents.

In Indiana this moraine presents considerable variation in contour, portions of it being a smooth ridge as in western Ohio, while other portions

are diversified by knolls. In southeastern Adams County, where the moraine enters Indiana, it consists of a ridge 30 or 40 feet in height with gentle swells and shallow basins on its crest and slopes, a subdued but characteristic morainic topography. No change is observed for about 4 miles west of the State line. Here a break occurs through which Indian Creek passes. West of this creek, in the southeast part of T. 25, R. 14 E., there is no definite ridge, and the swells rise but 10 to 15 feet above the Wabash bluffs. North of this point, along the line of sections 14 and 23 of this township is found the eastern end of a ridge which passes 2 miles or more WNW. to a small creek in section 16. This ridge has, in sections 14 and 23, a relief of 20 feet or more above the plains, both north and south of it, and is scarcely one-half mile in width. At the Wabash River, in section 16, it stands about 40 feet above the stream. In the northwestern part of this township there are several ridges one-half mile or more in length, each trending ESE. to WNW. They rise 15 to 20 feet above bordering low ground. They are most conspicuous in sections 5 and 8, but occur in sections 6 and 7. Northeast of these ridges are low swells and shallow basins extending beyond the village of Berne.

About 2 miles from the county line in sec. 22, T. 21, R. 13 E., the moraine again assumes a ridge-like form, rising abruptly 10 to 20 feet above the plain on the south, and carrying on its crest swells and sags with oscillations of 10 feet or more. Near the Adams and Wells county line it assumes much greater strength, there being knolls 30 to 40 feet in height that inclose basins and winding sloughs. The highest points stand probably 60 feet above the level of the Wabash bluff, which is less than a mile distant to the south. The knobs and basins are confined to a small tract scarcely a square mile in extent. Northwest of this, in Wells County, the moraine is in the form of a nearly smooth ridge, whose crest stands 40 to 50 feet above the Wabash bluff, and whose width, including slopes, is a mile or more. A break through which a creek passes occurs about 2 miles northeast of Bluffton. From this creek northwestward for 10 miles or more there is a series of swells and sags along a poorly defined ridge, the swells rising 10 to 15 feet, and occasionally 20 to 25 feet above the bordering sags. In T. 28, R. 11 E., a well-defined ridge or series of ridges appears, the most prominent of which passes through sections 13, 14, 15, 10, and 9. This ridge stands 30 feet or more above the plain on the south. It has

gentle swells and sags along its crest. There are minor ridges between Zanesville and Ossian on the north side of Eightmile Creek. This creek cuts through the main portion of the moraine at Zanesville, having here a valley fully twice as deep as it has on the plain which it enters west of the moraine. Between Zanesville and Aboit the moraine consists of a single ridge with slopes a mile or more in length. These slopes, as well as the crest, carry swells 10 to 20 feet in height. The ridge is distinctly maintained nearly to the old lake outlet south of Aboit. There the "Huntington wagon road" crosses it in sec. 17, T. 26, R. 11 E.; its altitude by pike survey is about 75 feet above the court-house square at Fort Wayne, and 30 to 40 feet above the altitude at the county line, $1\frac{1}{2}$ miles west of the crest. It is fully 100 feet above the lake outlet at Aboit.

The gap in the moraine through which this old outlet passes is $1\frac{1}{4}$ to $1\frac{1}{2}$ miles wide. The marsh which now occupies it is bordered by very abrupt bluffs, 50 to 75 feet in height, composed entirely of glacial drift. Just north of the outlet, near the mouth of Aboit River, several basins occur among the morainic knolls. They deserve especial attention, since such features are rare, saucer-like sags being the usual form, and these are not common. Dryer has published the following brief account of the group of basins referred to:[1]

> Upon the bluff near the mouth of the Aboit River (secs. 29 and 32, Aboit Township) there is an interesting group of typical potash kettles, seven within a space of about 30 acres. The largest forms an irregular depression 750 feet long, and from 100 to 200 feet wide. The rest are smaller, of oval or circular outline, and about 20 feet deep.

The northwest limb of this morainic loop consists, as a rule, of a series of swells and sags, and low, winding ridges which apparently have no uniformity of trend or system in their arrangement. Along Aboit River for several miles from the mouth of the stream knolls 30 to 40 feet in height are common. There has been much erosion along the north side of the lake outlet west of Fort Wayne, which obscures, to some extent, the morainic features, but 2 or 3 miles back from the outlet the morainic topography may be seen to good advantage. Throughout much of the tract in Allen and Dekalb counties the swells fall below 15 feet in height, but in northern Allen County there is a prominent ridge, known as "Dutch

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[1] Sixteenth Ann. Rept. Geol. Survey Indiana, pp. 121–122.

Ridge," which stands nearly 50 feet above the surrounding country. Also in southern Dekalb County, in the southwest part of T. 33, R. 13 E., knolls 30 to 40 feet in height occur. East of this prominent part of the moraine and near the line of Allen and Dekalb counties several marshes and sloughs were noted. They are narrow and look like obstructed valleys, though no connection with modern valleys could be found. East of these depressions is an undulatory till tract presenting oscillations of 10 to 20 feet in 20 to 40 rods.

In a trip from Butler south to the St. Joseph River near the State line a few swells 10 to 15 feet high and shallow basins 3 to 5 feet deep were noted, the sharpest knolls being in secs. 23 and 24, T. 34, R. 14 E. But slight though the undulations are they furnish a decided contrast to the very flat surface north of Butler and between Butler and Auburn, where a hummock or rise of ground as great as 5 feet in height is rare.

THICKNESS OF THE DRIFT.

In each of the moraines under discussion the thickness of the drift is perceptibly greater than on the plane tracts on either side, the difference being measured by the relief of the moraines. The relief, as has already been stated, ranges from 15 up to 50 or 60 feet, but the average relief is probably about 30 feet. The relief represents the increase in thickness beneath the crest, but on the slopes the amount of increase would be less. Assuming for each of the moraines an average breadth of 1½ miles the average thickness of the drift properly included in them would be not more than 20 feet.

The amount of drift deposited by various invasions and covered by this moraine ranges from 20 feet or less up to about 400 feet. The average thickness is probably less than 100 feet from the old lake outlet westward, but is much more than 100 feet from the outlet northward into Michigan. The thickness in the coalesced portion of this morainic series in northern Ohio is somewhat less than in the portion where the moraines are distinct in western Ohio, the amount on the elevated hills and ridges being seldom so much as 40 feet.

STRUCTURE OF THE DRIFT.

This moraine is preeminently a till tract, there being but few gravel knolls. It is known throughout much of its course as the "White oak ridge," since the forests along it are largely oak, while the bordering

plains carry a larger amount of beech, maple, elm, and other kinds of trees that flourish in a deep black soil, but do not find so good a habitat in the thin clayey soil of the moraine. Along a part of its course within the Scioto Basin, as indicated above, there is a prairie. The surface clay contains many pebbles, but bowlders are rare. A large proportion of the surface pebbles are crystalline rocks of Canadian derivation, and nearly all of the bowlders are of this class of rocks. The till is of a yellowish-brown color at surface, changing to a brighter yellow at a depth of 4 to 5 feet, and this in turn to a gray color at 10 to 15 feet.

The most conspicuous bowlder belts on this moraine are to be found along the Aboit River and the borders of the old lake outlet; elsewhere they are not a striking feature. The bowlders are mainly granites and are well rounded. But few show striated surfaces. These and other bowlder belts north of the old lake outlet have been interpreted by Taylor to indicate interglacial stream concentrations followed by readvances of the ice sheet.[1]

In the Ohio portion of the moraine scores of gas wells have been put down, for it passes through the Lima gas and oil district. Where best tested (in southeastern Allen County, Ohio), the thickness along the crest of the moraine is 60 to 100 feet, with an occasional greater thickness where a buried valley is struck. Thus, in the vicinity of Cridersville, a much greater amount has been penetrated in several of the wells; one, known as the George De Long well, is reported by Orton to have penetrated 428 feet, while the Lydia De Long well penetrated 335, and Cobb, Page & Co.'s well penetrated 300 feet. The buried valley in which these wells are sunk must be narrow, for within less than a mile in all directions rock is struck at 20 to 50 feet. Attention was called, on a preceding page, to wells south of St. Marys which passed through about 400 feet of drift, but the connection between these points has not been made out, though a connecting valley probably exists. Along the direct line through Wapakoneta and Moulton rock is usually struck at 80 to 150 feet, so that if it occurs along that line it must be very narrow. In the vicinity of the town of St. Marys the thickness of the drift ranges from 24 feet to over 400 feet. From St. Marys westward to the State line the general thickness along the moraine is about 60 feet, though there are places where it is

[1]Moraines of recession, etc., by F. B. Taylor: Jour. Geol., Vol. V, pp. 438–441.

much less, and rock is quarried both on the outer and inner borders of the moraine. There are also wells south of the moraine, as noted above, where the thickness of the drift reaches 400 feet.

Farther east than the Lima oil and gas field a few well sections were obtained that are worthy of note. In the valley of the River Styx, west of Wadsworth, Ohio, and 2 to 3 miles south from the outer border of this moraine, several flowing wells have been obtained from the drift. The deepest one visited is at Samuel Leatherman's. It has a depth of 107 feet. One at a schoolhouse is 62 feet in depth. One at Noah Baker's, 30 to 40 rods east of the schoolhouse and at about the same elevation, is only 42 feet in depth. The greater part of the material penetrated in these wells is described to be a blue clay free from pebbles. It is perhaps a silt similar to that exposed in the Cuyahoga bluffs, a description of which is given on a later page. The water rises in no case more than 7 and in some cases but 3 feet above the surface.

At Seville, in the valley of Chippewa Creek, an attempt was made some years ago to obtain an artesian well, but without success, though the water rose nearly to the surface. J. N. High, a hardware merchant in Seville, who supplied the drivepipe for the well, states that the total depth of the well was 336 feet, and that it penetrated the rock only about 50 feet. There is, therefore, about 300 feet of drift, and the altitude of the rock floor of the valley is scarcely 700 feet, the altitude of Seville station being 986 feet above tide.

At Sterling, 3 miles south of Seville, in the Chippewa Valley, and at an altitude about 960 feet above tide, there are 100 or more flowing wells which obtain water from the drift at depths ranging from 45 to 95 feet, the majority being 70 feet or more in depth. Mr. Lee, of Sterling, gave from memory the following section of the drift penetrated in a well at the gas works:

Section at gas works well at Sterling.

	Feet.
Soil of sandy nature	5
Clay of bluish color, about	20
Quicksand	6
Clay of blue color	20
Sand	10
Clay, about	30
Sand and gravel	4
Total depth	95

The clay is described as free from pebbles. It is usually blue, but it is stated to be nearly white in some of the wells.

A gas-well boring at Sterling is reported by J. E. Barnard, a resident of that village, to have penetrated nearly 400 feet of drift before striking rock. It passed through several alternations of clay and fine sand. The rock floor is here, therefore, at about the level of Lake Erie (573 feet above tide), though it is but a few miles from the continental divide. There are no borings either to the north or south along this valley in which a lower point in the rock floor has been struck, but the silty character of the drift seems to throw doubt upon the existence of a southward outlet. Toward the north there is a lowland tract connecting the head of Chippewa Creek with Rocky River. It seems not improbable that this may contain a channel deep enough to have been the outlet for this deep portion of the Chippewa Valley and that the divide at the time this valley was excavated lay south of Sterling.

A well at McVicker's hotel, in West Salem, is reported as not reaching rock at a depth of 80 feet. This is located between the Wabash and St. Marys moraines. At Savannah wells strike rock at from 15 to 30 feet. The drift is mainly till.

At E. Murray's, 4 miles west of Savannah, on the crest of the Wabash moraine, rock is struck at 50 feet, and on a neighboring farm, also on the morainic crest, at 42 feet. About one-half mile north of the crest, on lower ground, Mr. Murray's well struck rock at 20 feet and obtained a flow of water from that depth. At Adario, about a mile southwest of Mr. Murray's, on the outer border plain, some flowing wells have been obtained from the drift at a depth of 20 feet.

Near Greenwich the drift has been penetrated 65 to 100 feet by water wells without reaching rock, but in places in and near that village rock is struck at about 35 feet.

At Shiloh wells 40 to 45 feet deep have been made, none of which reach rock. Three miles north of Shiloh rock is struck at 20 feet, and there are outcrops along Black Fork, on the outer border of the moraine, a few miles southeast of Shiloh.

At Plymouth, in the midst of the moraine, there are rock quarries on ground but little lower than the bordering moraine, but in the western part of the village, near the public square, wells penetrate about 80 feet of drift.

At Shelby, which lies on the outer border plain, near the moraine, rock is struck in gas wells at about 50 to 60 feet, the drift being almost entirely till.

At Sulphur Springs, in the midst of the Wabash moraine, 5 to 6 miles northeast of Bucyrus, a well at Dr. J. B. Squires's, 60 feet in depth, does not reach rock. There are several flowing wells in this village whose depth is about 30 feet. They are in a sag, and water rises but a foot or so above the surface. The source of supply is probably from higher parts of the moraine toward the south and east.

At Bucyrus the drift is 25 to 40 feet thick, mainly till. This city stands on the outer border of the moraine.

In Nevada a gas well penetrated 27 feet of drift. Its mouth is 10 to 12 feet below the level of the railway station. About a mile above Nevada rock appears in the bed of Brokensword Creek, and for several miles above that point is exposed in the bed and bluffs. This is between the Wabash and St. Marys moraines.

A well at the village of Wyandot, in the street, near crossroads, struck rock at 80 feet. There was some till, but much of the drift was sand. The well mouth is at least 50 feet above the Sandusky River, and is on the crest of the moraine.

At Morral the town well struck rock at 50 feet, the drift being mainly till.

At Cochranton the gas well struck rock at 50 feet. Several flowing wells in the village obtain water from drift gravel beneath blue till at a depth of 40 to 45 feet. Wells on the prairie, for 3 to 4 miles north from Cochranton, strike rock at 35 to 50 feet.

At Agosta wells on the moraine strike rock at 50 to 55 feet; the drift is mainly till.

In the Scioto Valley, south of Kenton, rock is struck at 12 to 20 feet. This is at a level about 60 feet lower than the crest of the moraine. On the north slope of the moraine two wells north of Kenton struck rock at 30 to 45 feet, or about the same level as in the Scioto Valley south of Kenton. No records were obtained of borings in Kenton showing the thickness of the drift on the crest of the moraine. In case the rock is as low here as on the other side, which is not improbable, the drift has a thickness of about 75 feet.

In the Indiana portion of the moraine the following include the deepest well sections obtained: On a plane tract north of the moraine in sec. 31, T. 26, R. 15 E., David Studebaker made a boring for oil which penetrated 52 feet of till and 18 feet of sand before striking the Lockport (Niagara) limestone. Six miles south from Studebaker's, on the crest of the moraine, in sec. 32, T. 25, R. 15 E., G. Cramer made one well which entered rock at 60 feet and another at 51 feet. In each there is about 40 feet of till, below which is sand and gravel. A mile south of Mr. Cramer's there are quarries. At Geneva, only 5 miles west of these quarries, on ground equally low, the drift is 390 feet in thickness. A gas boring made here penetrated 80 feet of till, below which for 310 feet there is reported to be nothing but sand. The first rock encountered was the Hudson River shales, the overlying limestone being entirely removed. On a preceding page attention was called to the connection of the valley here struck with an equally deep one at the Grand Reservoir in western Ohio. The Wabash River is now flowing, in this portion of its course, in a postglacial valley near the level of the rock surface of preglacial uplands, for the bed in several places has a rocky floor, but the bluffs are entirely of drift. Throughout much of its course from the State line to Huntington the bluffs are very low, averaging scarcely 30 feet in height.

On the crest of the moraine 1½ miles west of the Adams and Wells county line a well strikes limestone at 92 feet, the following being its section:

Well on Wabash moraine in eastern Wells County, Ind.

	Feet.
Yellow till	15
Blue till	45
Gravelly clay with beds of clear gravel	32
Limestone	7
Total	99

At Kingsland, in Wells County, a village situated near the inner border of the moraine, one well strikes limestone at 80 feet, but another of the same depth enters a water-bearing gravel at the bottom. At each well there was about 15 feet of yellow and 65 feet of blue till. A few miles west of Kingsland, near Uniondale, on the outer border of the moraine, rock has been struck in several places at 40 feet or less, and in one instance at 18 feet. The drift here consists of 10 to 20 feet of till underlain by fine

gravel. Wells on the moraine north of Uniondale strike rock at 50 to 70 feet. They are through till nearly the whole depth, but some of them pass through thin beds of sand just above the rock.

A well in Allen County, on the crest of the moraine, in sec. 17, T. 29, R. 11 E., 102 feet in depth, does not reach the bottom of the drift; it is mainly through till. A well one-half mile east, and perhaps 15 feet lower at surface, penetrates 73 feet of till, beneath which is gravel which becomes wate bearing at 85 feet from the surface.

North of the old lake outlet in Allen County wells are ordinarily obtained at 30 to 40 feet or less. They seldom penetrate much sand or gravel. The yellow till is 10 to 20 feet thick, being shallowest beneath level or low portions and deepest in the swells. It changes at these depths to blue till. On the plain northwest of the moraine, near Dunfee station, several wells are 60 feet and one 127 feet in depth. In all of them the greater part of the section is till, which is reported to be very hard and dry and of a blue color from within 10 feet of the surface. Near Huntertown, in section 4, Perry Township, and on the plain just outside the moraine, a boring for gas passed through 281 feet of drift. It penetrated yellow and blue till to a depth of 20 feet, beneath which the section is mainly sand and gravel. At Auburn and Butler gas wells penetrated equally large amounts of drift, as reported above (p. 504).

INNER BORDER PHENOMENA.

In Adams, Wells, and southern Allen counties, Ind., and Mercer County, Ohio, the moraine is bordered on the northeast by a nearly plane till tract, which has a gradual descent to St. Marys River, while in Auglaize and Allen counties, Ohio, there is a similar descent to Hog Creek. Between the head of Hog Creek and the Sandusky River a plain extends northward several miles, the Fort Wayne moraine being very weakly developed there; but from Wyandot eastward, as already noted, the Fort Wayne moraine is separated but a short distance from the inner border of the Wabash moraine.

There are occasional swells 10 or 15 feet high on the inner border plain, but nearly the whole of the surface is so flat that large open ditches have been made to carry off the surplus rainfall. A black soil 1 to 2 feet or more thick covers the greater part of the plain, and beneath this is a yellow clay, which contains fewer pebbles than are ordinarily found in the

surface till. A laminated structure was observed in a few places, and it is not improbable that it is a subaqueous deposit, made perhaps during the retreat of the ice sheet from the Wabash to the St. Marys moraine. If the retreat was such as to block the western outlet, lakes may for a time have been held between the ice sheet and the Wabash moraine. No exposures were afforded by which determinations of the thickness of the deposit could be made, but, judging from well sections reported, it is at most but a few feet.

The forest on this plain contains beech, maple, elm, ash, etc., with but little oak, and in this respect the area presents a striking contrast to the oak-covered moraine.

In northern Allen and Dekalb counties this moraine is separated from the Fort Wayne only by the narrow valley of the St. Joseph River, and the phenomena along this river valley are discussed in connection with the latter moraine.

OUTER BORDER PHENOMENA.

From near Mansfield, Ohio, westward to the old lake outlet there is a plain similar to the plain on the inner border, just described, having a deep black soil, heavy forest, and a clay subsoil which appears to be, in part at least, of subaqueous origin. There is remarkably little coarse material along valleys, and glacial outwash seems to have been weak. Gravel deposits occur along the Wabash River below Bluffton, Ind., but were not observed above that city. Their relation to the moraine was not satisfactorily determined. In southern Dekalb and northern Allen counties, Ind., a gravel plain extends from Big Cedar Creek southwestward past Huntertown to the head of Eel River. A portion of it is dry and sandy, but much of it is poorly drained and is known as the "Huntertown marshes." It appears to have been a line of discharge for the waters of the ice sheet at the time the Wabash moraine was forming. The ice sheet probably had at that time a line of discharge down the old lake outlet to the Wabash, but subsequent erosion has swept the valley so clean as to remove such evidence of discharge as may have existed.

Eastward from Mansfield the outer border district presents much variation in features, and a more detailed description seems necessary than is required for the smooth district to the west. The features of the uplands lying south of the eastern part of this moraine are discussed in connection

with the moraines of the Scioto lobe. It is necessary here to consider only the valley drift phenomena, which have a bearing upon the drainage of the ice sheet at the time the moraine was forming. In some of these valleys, as will appear from the description, the evidence of outwash from the ice sheet is clear and unmistakable, while in others the phenomena are less clear in their import.

The easternmost valley through which the glacial waters could have found escape to the southward is the one passing from the bend of the Cuyahoga through the city of Akron to the Tuscarawas River, crossing the Lake Erie–Ohio divide at Summit Lake This valley carries heavy deposits of gravel and sand that are of glacial age, a portion of its gravel plain being indented with deep basins such as often characterize the outwash aprons along moraines, and which are not known to occur except in glacial deposits. The valley has evidently at some time been the avenue for the discharge of glacial waters, but on account of the great amount of erosion which has taken place in it near the bend of the Cuyahoga the connection with the morainic series under discussion is not clear. It may possibly be of greater age. A chain of knolls and ridges of morainic type occurs along the western border throughout nearly its entire course, which, though forming a very feeble moraine, may indicate the position that the ice margin occupied while the gravel plain was being formed. The northernmost occurrence of the gravel plain is found in a remnant north of the city of Akron, a very level tract extending southward from the bend of the Cuyahoga along the east side of the Little Cuyahoga to the northern part of the city (Akron on the Heights), where it is cut off by the Little Cuyahoga Valley. Its altitude is about 1,000 feet above tide. It reappears on the south side of the Little Cuyahoga, passing through the western part of the city, along the west side of the Ohio Canal. In this portion it is characterized by numerous basins, which are most abundant on its western border next the chain of morainic knolls just referred to. Farther south it is followed by the canal and extends some distance to the east of it, and includes larger basins, a few of which contain water, as Summit Lake and a chain of lakes leading south from there to the Tuscarawas River.

A valley just west of Akron, leading southward through Copley Marsh to the Tuscarawas from near the head of the Cuyahoga, has gravel deposits in it that head in the morainic series on the continental divide. The

head, or north end of the gravel plain, is known as Ayer Flats. It is crossed by the Northern Ohio Railroad, whose profile shows its altitude to be 998 feet above tide, or about 425 feet above Lake Erie. There is a gradual descent southward through Copley Marsh to the Tuscarawas River, near New Portage, the altitude of the outlet of Copley Marsh being 400 feet above Lake Erie. The gravel on Ayer Flats is rather fine, having few pebbles exceeding an inch in diameter, but is composed of well-assorted material. There are numerous basins in the plain, depressed 4 to 8 feet below its surface, each an acre or more in extent. The deeper ones have about the level of the north end of Copley Marsh. This marsh is covered with so heavy a deposit of peat and muck that the ditches which drain it (2 to 4 feet in depth) do not reach the bottom. As stated on a previous page, a boring near the southern end of the marsh penetrates about 400 feet of drift, mainly silt. This is the only deep boring yet made in the valley. It is probable that the silt extends northward beneath the gravel of Ayer Flats and the till of the moraine that lies just north of these flats, connecting with the silt deposits along the Cuyahoga.

In Sharon Township, Medina County, a small tributary of the Tuscarawas emerges from the moraine. Its valley contains gravel deposits below the point of emergence, but their surface is not so level as terrace deposits usually are, and it seems probable that they were an incident of the retreat of the ice sheet rather than an outwash from the moraine.

In the valley of the river Styx there is a broad marshy plain a mile or more in width, which heads in the moraine near the village of River Styx. It is underlain by a mucky clay and appears to have but little gravel on its surface. In crossing the valley, 4 miles below River Styx village, low gravelly ridges and knolls were observed on both its eastern and western borders, but they have not the level surface of the ordinary terrace, and are probably deposits incident to the retreat of the ice sheet.

In Chippewa Valley, from Seville southward beyond Sterling, there are low sandy knolls 3 to 5 feet and occasionally 10 feet in height, which, together with a slight deposit of sandy clay, rest upon the silt deposits with which the valley was filled. The knolls may possibly have been formed by the agency of wind. The material was probably contributed as a quiet outwash from the moraine.

On Killbuck Creek there is an open plain extending up to the Fort

Wayne moraine, and no terraces were found connecting with the Wabash moraine.

In the valley of Lake Fork, near Pleasant Home, there is a pitted gravel plain with basins 3 to 4 feet deep, which has a sufficiently close connection with the Wabash moraine to render it probable that it was produced by the escape of glacial waters at the time the moraine was forming. The gravel plain does not, however, fit closely against the moraine, there being the valley of a tributary of Lake Fork between the head of the gravel plain and the outer border of the moraine. At its head the gravel plain stands about 25 feet above the flood plain of Lake Fork. It is composed of gravel of medium coarseness, few pebbles exceeding 2 inches in diameter. The pebbles are well rounded and the gravel is almost free from earthy material from near the top to the bottom, there being in places scarcely enough earth on top to form a soil. A few miles below, this gravel plain descends nearly to the level of the creek, and the stream is bordered by an open marshy valley until the earlier moraines and their terraces set in.

On a tributary of Lake Fork which leaves the Wabash moraine just west of the Wayne-Ashland county line there is a terrace standing about 25 feet above the creek. It has its head at the moraine just north of the Ashland and Pleasant Home road. No basins were observed at the head of this terrace.

In the valley of Jerome Creek, north and east of Ashland, there are numerous knolls or island-like elevations. They are, perhaps, remnants from erosion, though some appear to be glacial aggregations, such as those in certain valleys of Medina County, which are considered incidents to the retreat of the ice sheet. One of these knolls, about 2 miles east of Ashland, carries a basin near its crest, a feature which negatives the hypothesis that the knoll is a product of erosion. The knolls are elongated in the direction of the valley—northwest to southeast. They stand 15 to 25 feet above the present flood plain. Some of them have a nucleus of clay and a capping of fine gravel; others seem to be composed largely of gravel and sand. This valley is characterized by such knolls throughout nearly its entire length, the source of the creek being near the outer border of the Wabash moraine. At the border of the moraine there are basins as well as knolls. The knolls rise abruptly 10 to 25 feet above the basins and are rather gravelly. Among the knolls are swales or marshy tracts which broaden out in places

to extensive marshes. It is probable that the ice sheet had a discharge for its waters down this creek, and the marshes and lowland tracts may represent the channels occupied by the glacial waters.

Black Fork Valley, from the point where it touches this moraine (south of Shiloh) southeastward, contains numerous knolls, which give it an appearance somewhat similar to the valley of Jerome Fork just described. It, however, soon enters the main morainic system of the Scioto lobe, and these knolls may, perhaps, form a portion of the inner member of that system. It is probable that the ice sheet had a line of discharge down this valley while forming the Wabash moraine, but it was not sufficiently strong to clear the valley of its drift knolls and form conspicuous terraces.

There was found along the Scioto Valley no decisive evidence of vigorous drainage from this morainic series. Gravel and sand are exceedingly rare, and what little silt there is in this outer-border district may be independent of the moraine. The lack of evidence of drainage from this portion of the ice margin is difficult to explain, especially since no barrier appears to have existed along the course of the Scioto below the moraine which could have checked the drainage. As previously noted, there are extensive prairies on the eastern slope of this basin. They present a plane surface and are covered with a black soil, but the soil is apparently till to which carbonaceous matter has been added. Furthermore, they are not level, there being an eastward rise of 100 to 150 feet from the axis of the basin to the east border of the prairies.

ST. MARYS OR FORT WAYNE MORAINE.

This moraine was given the name St. Marys by Gilbert from its relation to the St. Marys River, whose course it governs for about 60 miles. But as the town St. Marys, Ohio, is on an earlier moraine, the name has led to some confusion. In consequence of this, the name Fort Wayne, taken from the most prominent city on the moraine, is supplementing the old name. Gilbert recognized and named the moraine at the time he made a survey of western Ohio in 1869 and 1870. It is, therefore, one of the earliest recognized moraines on this continent.[1] It was Gilbert's conception, however, that the

[1] The result of Gilbert's investigations in northwestern Ohio appear in two places: First, in the American Journal of Science for May, 1871, where a brief account only is given; second, in Vol. I of the reports of the Ohio Geological Survey, which was published in 1873, and which contains a somewhat detailed account of the region.

moraine itself is not visible, but is concealed or blanketed by a heavy deposit of Erie clay, a deposit supposed at that time to have been of iceberg origin and of much later age than the glacial drift. It is but fair to state that this conception is now abandoned by its author, for subsequent studies failed to disclose any essential difference in structure between the superficial and the deeper portions of the drift, while the drainage phenomena show that at the time these moraines were forming the altitude was so great as to render inapplicable the theory of large inland seas in Ohio and Indiana. There could, therefore, have been no extensive sheets of iceberg drift. The questions of the probable altitude of this region and the extent of lakes in it are discussed on a later page.

N. H. Winchell has included a description of this moraine in a paper on the surface geology of northwestern Ohio, already mentioned.[1] Dryer has given a description of the Indiana portion of the moraine in his report on Allen County, Ind.[2]

DISTRIBUTION.

As indicated above, the Fort Wayne moraine is closely associated with the Wabash moraine from the interlobate tract west of the Grand River Basin in northeastern Ohio westward to the Sandusky River near Upper Sandusky. For a few miles west of Sandusky River there is scarcely any development of morainic features, but near Dunkirk the Fort Wayne moraine appears in strength and follows the north side of Ottawa River (or Hog Creek) westward, determining the course of the river from Hog Creek marsh in Hardin County to the bend just west of Lima. The moraine then turns westward, crossing Auglaize River at Fort Amanda and coming to the St. Marys at the bend near Kossuth. From Kossuth it follows the northeast side of the St. Marys to its mouth at Fort Wayne, Ind. From Fort Wayne, as outlined by Gilbert, its course is northeastward along the east side of the St. Joseph River to the vicinity of Hudson, Mich., near the head of that stream, beyond which its course and connections are not fully determined.

From the Sandusky River eastward the moraine, where distinct from the Wabash moraine, is usually but 1 to 2 miles in width. But on the east side of the Sandusky River it has a spur which extends north 10 miles or more to the vicinity of the Defiance, or next later moraine.

[1] Proc. Am. Ass. Adv. Sci., 1872, pp. 168–171.

[2] Sixteenth Ann. Rept. Geol. Survey Indiana, 1889, pp. 114–115.

The general width of the moraine from Hog Creek marsh westward nearly to the State line of Ohio and Indiana is but 1 to 2 miles. It there shows a marked increase in breadth, and throughout much of its course in Indiana presents a breadth of about 4 miles, not including the long inner slope. In the earlier moraines—the Union, Mississinawa, Salamonie, and Wabash—the greatest breadth is found along the southern border of the ice lobe instead of the southwestern border. It is thought that this difference may be occasioned by the ice movement, the broad portions being at the terminus of the axial or strong movement, while the narrow portions mark the terminus of the lateral or weak movement. At the time the Fort Wayne moraine was forming the axial movement appears to have been southwestward, or in about the direction of the trough of the Erie-Maumee Basin. It seems, therefore, but natural that the moraine should be broadest at the end of that trough. At the time the earlier moraines were forming the ice appears to have moved strongly toward the Scioto and Miami basins and to have been controlled less by the Maumee trough; hence the great strength of these moraines around the southern end of the loops.

In the distribution of this moraine Gilbert found the key to the peculiar course of the St. Marys and St. Joseph rivers. On this subject he says:[1]

North of the Maumee the general descent is to the southeast, and south of that river to the northeast. With slight exceptions, the smaller streams follow and indicate these slopes, but all the larger tributaries of the Maumee, including the St. Joseph, St. Marys, and Auglaize rivers, and Bean or Tiffin Creek, appear to be independent of them. The St. Joseph, for example, flows to the southwest, through a country where every rivulet runs to the southeast. The entire region drained by it lies on its right bank, while from its left the drainage is toward Bean Creek, the divide between the two streams being everywhere within 3 or 4 miles of the St. Joseph. In like manner the course of the St. Marys is west and north, and while from its left bank the streamlets flow northeast into it, from the right they flow northeast into the Auglaize. These hydrographical peculiarities, which may readily be noted on the accompanying map, are so singular and striking as to have excited some attention and curiosity before the region was visited. Upon examination there was found a continuous ridge following the eastern banks of these rivers and evidently determining their courses. Running somewhat obliquely across the slopes of the country, it turned aside all the small streams and united them to form the St. Joseph and St. Marys. The height of this ridge is ordinarily from 25 to 50 feet

[1]Geology of Ohio, Vol. I, 1873, p. 541.

and its width at base from 4 to 8 miles. Along the St. Joseph it is not distinguished from the adjacent country by its superficial characters. In common with that, it has a gently rolling surface with a gravelly clay soil supporting a heavy growth of varied timber. Farther south, where it forms the north bank of the St. Marys River, in Van Wert and Mercer counties, it is marked by such peculiarities as to divide it very sharply from the adjoining plains, which are nearly level, with a soil of fine clay and covered by a heavy growth of elm, beech, ash, maple, etc. The ridge, on the contrary, presents a confused series of conical hills, chiefly of clay, but showing some pebbles and small bowlders and clothed by forest growth, almost exclusively of oak. Probably the only essential point in this contrast is that of hill and plain, and out of this the others have grown

RELIEF.

In the Ohio portion of the moraine, except near the State line, the relief is somewhat abrupt, the moraine being narrow, and amounts to 20 to 30 feet. In the Indiana portion, owing to the greater breadth of the moraine, the relief is not so striking, though its amount is greater than in Ohio, the altitude of the crest being 30 to 50 feet, or even more, above the bluffs of the St. Marys and St. Joseph rivers on the outer border plain.

RANGE IN ALTITUDE.

The range in altitude along the crest, aside from the channel at Fort Wayne, is about 400 feet. Including this channel it amounts to about 450 feet. There is a descent toward the old-lake outlet, both from the north and the east, but it is so gradual as to be scarcely perceptible. East of the head of Sandusky River the moraine crosses a series of ridges and lowlands which cause abrupt variations of 200 to 300 feet. The following altitudes, compiled from various sources, serve to illlustrate the above statement:

Table of altitudes along the Fort Wayne moraine.

Station.	Authority.	Altitude above tide.
		Feet.
Chippewa, Ohio	Cleveland, Lorain and Wheeling R. R	1,056
Harrisville Marsh	Ohio Geological Survey	913
Burbank	Erie R. R.	957
West Salem, north of	Barometric	1,160
Sullivan, south of	Estimated	1,220
Nova, south of	Barometric	1,180
Savannah Lake	Barometric	1,060

Table of altitudes along the Fort Wayne moraine—Continued.

Station.	Authority.	Altitude above tide.
		Feet.
Greenwich, high points southeast of	Estimated	1,125
Greenwich	Big Four R. R	1,037
Plymouth	Baltimore and Ohio R. R	993
New Washington	Northern Ohio R. R	999
Summit near Chatfield	Northern Ohio R. R	1,017
In Sandusky Basin	Estimated	850–925
Near Dunkirk	Pittsburg, Fort Wayne and Chicago R. R	950
Dunkirk, Ohio, one mile north of	Estimated	975
Lima, Ohio	Several railways	875–885
Two miles south of Spencerville	Miami Canal Survey	872
Ohio City, Ohio, south of	Estimated	875
Decatur, Ind., east of	Chicago and Erie R. R	862
Adams and Allen counties line, near	Grand Rapids and Indiana R. R	846
Fort Wayne, southeast part of	Estimated	820
Fort Wayne (court-house)	City engineer	772
In lake outlet, head of Maumee River	City engineer	737
West of Hicksville, Ohio	C. R. Dryer	849
Crossing of Baltimore and Ohio R. R	S. W. Hartwell	902
Bryan, Ohio, west of	Lake Shore and Michigan Southern R. R	873
Hudson, Mich	Lake Shore and Michigan Southern R. R	945

TOPOGRAPHY.

The well-defined crest which this morainic belt displays constitutes the most marked as well as most constant feature, yet it is seldom sharply ridged. In places sharp knolls 10 to 20 feet in height occur, but they are not a common characteristic feature, the greater part of the surface being very gently undulating with oscillations of but 5 to 10 feet in a distance of 10 to 20 rods. Shallow basins are common, but they are usually saucer like in form, and seldom have the depth or the abrupt borders of the basins in knob-and-basin morainic topography.

The variations in topography will appear in the description which follows. This description begins at the eastern end, near the Cuyahoga Valley, and passes westward along the moraine. On the uplands east of the Cuyahoga Valley south of Medina the moraine consists of a swell-and-sag tract, in which few swells exceed 15 feet in height, though there are many ranging from 8 to 10 feet. There is a slight tendency to ridging in

an east-northeast to west-southwest direction—i. e., in line with the trend of the moraine—but only for about a half mile in a place, the belt in that vicinity being generally without distinct ridge or crest.

In the valley to the west, in which Chippewa Lake lies, the moraine has scarcely as many knolls as are found on the uplands, and, so far as observed, they are all low—15 feet or less in height.

From Chippewa Lake southwestward to Burbank the moraine has a patchy development, being interrupted by broad marshy tracts on the lowlands and but feebly developed on the uplands Upon leaving Killbuck Creek, near Burbank, its expression becomes stronger, and throughout much of the distance westward to the Scioto-Sandusky Basin it has greater strength than the Wabash moraine and is less irregular in its features. Its surface is billowy, being seldom sharply ridged. The knolls are 10 to 25 feet in height and so closely associated as to leave but little plane surface among them.

From Lake Fork westward to Plymouth the Fort Wayne lies immediately north of the Wabash moraine; but east from Lake Fork it is quite distinct from the Wabash belt for several miles, there being a nonmorainic interval 1 to 3 miles wide, and westward from Plymouth it is distinct all the way to the Sandusky River, there being a plain 1 to 3 miles wide between the moraines, through the midst of which Brokensword Creek has its course.

From Plymouth westward to the Sandusky River the Fort Wayne moraine has frequent developments of ridges which correspond in trend with the course of the moraine, being nearly east to west in the vicinity of New Washington and Chatfield and northeast to southwest a few miles farther west, near Seal, where the moraine curves toward the southwest. It has also numerous knolls 10 to 20 feet high and a well-defined and, in places, very abrupt outer border relief of 20 to 30 feet. This portion of the moraine is in strong contrast with the very flat tracts that border it on either side.

From the curving portion of the moraine, near Seal, a spur runs out to the northwest or nearly at a right angle to the trend of the moraine. It occupies much of the interval between Sycamore Creek and Sandusky River, a breadth of 4 or 5 miles, and extends to the bend of the Sandusky at McCutcheonville, a distance of fully 10 miles from the moraine, where it

touches the outer border of the Defiance moraine. This spur occupies a slightly depressed tract, compared with the region on the east, its highest points rising scarcely to the level of the plain east of it; but it is fully as high as the plain west of it. Basins are a conspicuous feature, and they are associated with knolls and winding ridges in characteristic morainic fashion. At the northwest end of the spur, along each side of the Sandusky River, there are ridges whose trend is northeast to southwest, or nearly parallel with the moraine and at right angles to the spur. They rise abruptly 15 to 20 feet above the till plain that lies west of the Sandusky. East of Mexico and near the outer border of the Defiance moraine is a district where the knolls and basins are very sharp, presenting a strong contrast to the gently undulatory topography of the Defiance moraine. As stated above, the spur is traceable up to that moraine and may have extended still farther to the north along Sandusky River and have had its northern portion overridden by the advance of the ice sheet which produced the moraine.

The Fort Wayne moraine crosses the Sandusky River at Little Sandusky, and has a remarkably feeble development from there westward around the end of the loop. A low ridge passing southwestward near Moral and Cochranton completes the eastern limb of the moraine. From Cochranton to Dunkirk there are only patchy developments of morainic topography which in themselves would hardly be considered sufficient to be classed as a moraine, but which serve as the connecting links between the well-defined portions to the east and to the west.

About 1½ miles east of Dunkirk a well-marked drift ridge sets in, which for 2 or 3 miles has a course north of west. It then assumes a nearly due-west course, which it maintains for fully 10 miles, when it curves to the south of west and follows the north side of Hog Creek to Lima. Before reaching Hog Creek it is bordered on the south for a few miles by Hog Creek Marsh. It has a well-defined crest standing 20 to 40 feet above the outer border plain, and is dotted by low swells 5 to 10 feet in height. Its breadth is scarcely half as great as that of the portion of the moraine east of Sandusky River, being but a mile, or even less. From Lima westward the moraine maintains a well-defined crest, but it is not so sharp as it is east of that city. It is dotted by low swells, scarcely 10 feet in usual

height. There is a cluster of sharp knolls east of Decatur, Ind., but few of them exceed a height of 15 feet. They are abrupt and inclose numerous basins, and there is, in addition, an unusual number of surface bowlders which add to the morainic expression.

The moraine has been deeply channeled by water in the vicinity of Fort Wayne. The most important channel is the lake outlet, which has, in its passage through the moraine, opened a valley about 1 mile in width, and 30 to 50 feet in depth, its depth at the head of the Maumee being 35 to 40 feet.

A smaller channel, known as the Sixmile Channel, traverses the moraine a few miles southeast of Fort Wayne and furnishes a much more direct course than the present one for the St. Marys River. It leaves the St. Marys about a mile below Hesse Cassel, in section 7, Marion Township, and passes in a course east of north to the Maumee River just west of New Haven. Its summit is reported by Dryer to be but 10 feet higher than the St. Marys River, and in flooded seasons the river discharges a portion of its waters through this channel. Except at its north end, where it is somewhat expanded, the channel has a width of only one-fourth mile, and its banks are estimated by Dryer to be 15 feet in average height, though the portion of the moraine on the east soon rises along the line of the Pittsburg, Fort Wayne and Chicago Railroad to a height of 40 feet, and that on the west to a height of 60 feet above the channel. The low tract which this channel follows was apparently occupied for a time as an outlet for Lake Maumee, as indicated more fully on a later page.

The continuation of Sixmile Channel is westward down the St. Marys River to section 26, Wayne Township, about 3 miles south of Fort Wayne. The river there turns northward while the old channel continues westward and joins the outlet in the southwest corner of the same township. This part of the channel is one-fourth mile or more in average width and stands about 15 feet above the present river bed. It is a marshy tract, apparently filled to some depth with sediment, and has distinct bluffs only on its southern border, where there is an abrupt rise of 15 to 20 feet.

In the triangular tract bounded by this marshy channel, the old lake outlet, and the St. Marys River, there is a district comprising several square miles which stands considerably above the channels, its highest points

reaching an altitude of over 800 feet, or about 50 feet above the bordering marshy tracts and fully 60 feet above the St Marys River, while the greater part stands 20 to 30 feet above the marshy tracts that border it. It is traversed by sandy ridges, to which Dryer has given attention, and which have received individual description in his report on Allen County, Ind.[1] The ridges are in some cases about a mile long and have a tendency to trend east-northeast to west-southwest, but various other trends are assumed by the different ridges. In some cases there is a main ridge from which branches lead off at nearly a right angle. The ridges are 10 to 30 feet in height and vary in width from a few rods up to nearly one-fourth mile. There are similar ridges on the crest of the moraine in the east part of Fort Wayne. The most prominent one is estimated by Dryer to have had a height of 30 feet previous to its removal by the railroad. The portion remaining (east of the freight yards) stands about 15 feet above the bordering portion of the moraine. This ridge has an east-west trend, parallel with the lake outlet and at a right angle to the crest of the moraine. It was originally a mile or more in length (Dryer), but the greater part is now removed. Similar ridges also occur in the west part of Fort Wayne on the east bluff of the St. Marys River. They follow the bluff in a curving course from southwest to northeast. These ridges seem to be due in large part to the work of wind upon sand that was deposited in the outlet. This interpretation, it will be noted, differs from that given by Dryer in the report above cited, it being his opinion that they are of glacial origin.

The portion of this moraine north of the outlet, as noted by Gilbert, is less strongly in contrast with the adjacent plain from Fort Wayne northeastward than in the portion bordering the St. Marys River, though its surface is "gently rolling."[2] It presents but little variation from Fort Wayne northeastward across northwestern Ohio into Michigan.

THICKNESS AND STRUCTURE OF THE DRIFT.

From the eastern end in Ohio westward to Decatur, Ind., the general thickness of the drift (not including that in buried valleys), is scarcely twice as great as the relief of the moraine, there being numerous outcrops of rock along the shallow valleys that follow the outer border of the moraine, while the wells along the moraine and on the border plain often

[1] Sixteenth Ann. Rept. Geol. Survey Indiana, 1889, pp. 116–118. [2] Geology of Ohio, Vol. I, 1873, p. 541.

strike rock slightly below the level of the base of the ridge. In buried valleys the drift in places reaches a depth of about 300 feet, as has been shown in the discussion of the Wabash moraine. In Allen County, Ind., and in northwestern Ohio the thickness greatly exceeds the amount represented by the relief of the moraine, the average thickness at Fort Wayne being about 100 feet on the moraine and 50 feet or more along the lake outlet, while in northwestern Ohio the thickness, as indicated by gas wells at Hicksville and Bryan, is 150 to 200 feet, or at least four times the amount of the relief of the moraine.

In the portion where the drift is mainly comprised in the morainic ridge there is but little assorted material, the body of the ridge being a stony blue till, but where the drift extends much below the level of the base of the ridge it is apparently composed largely of sand and gravel in its lower portions.

Gilbert called attention, in his report for the Ohio survey noted above, to the more stony character of the surface portion of the moraine compared with the surface portion of the bordering plain. The difference was attributed by him in the main to changes produced by subaerial erosion. It seems probable, however, that there was also an original or inherent difference, it being natural that the moraine should carry a larger proportion of stony material in its surface portions than the plains, or rather that it should carry less fine material, owing to the extraction and removal of such material by the water escaping along the ice margin. So far as known the deeper portions of the drift present no marked differences in the two situations.

The yellow till which constitutes the surface portion of the drift is 8 to 12 feet in thickness. In common with the surface clays of the other moraines of this region it is not deeply oxidized, the color being a grayish rather than brownish yellow.

Gilbert's report contains the results of an actual count of pebbles included in a sample of the surface till from near Edgerton, there being in a total of 155 pebbles 24 chert, 19 limestone, 22 quartzite, and 90 gneissoid specimens. This count displays a very large preponderance of distantly derived material, a much larger proportion than was found by the same observer in deeper portions of the drift, there being near the base of the drift at Toledo 80 per cent of nonmetamorphic or somewhat local pebbles, and only 20 per cent of metamorphic or distantly derived pebbles. In

view of the results of counting several samples from different horizons in the drift, Gilbert remarked as follows:[1]

> These figures give numerical expression to a fact that has been confirmed by the inspection of the surface over large areas, and of the lower portions at many points—the fact that the Laurentian rocks predominate over the ordinary sedimentary in the upper portions, while the reverse is true in the lower, and the intermediate parts present a gradation. When a gravel bed occurs near the base of the deposit it is usually, though not invariably, made up of fragments, little worn, of the rocks on which it rests.

The following represent the more important well records obtained west from the point where the Wabash and Fort Wayne moraines become widely separated. Sections of wells in the portion that is closely associated with the Wabash moraine are presented in the discussion of that moraine.

On the crest of the Fort Wayne moraine north of Dunkirk, Ohio, two wells at J. P. Dixon's strike rock, one at 44 feet, the other at 46 feet. One mile east, and also on the crest, a well at J. M. Reed's struck rock at 50 feet. In all these wells the drift is almost entirely till. Still farther east (in sec. 9, Blanchard township) A. Gillen has a well which struck rock at 60 feet, while Mr. C. F. Darrett (in sec. 16, Blanchard township) has a well with 100 feet of drift.

On Hog Creek Marsh, near Dunkirk, several flowing wells have been obtained at 30 to 35 feet, from gravel below blue clay.

At Lima the drift generally has a thickness no greater than the relief of the moraine (about 20 feet), but in one boring within the city limits 170 feet is reported. It is somewhat thicker than 20 feet south of Spencerville, there being no rock exposed by the Miami Canal, which is excavated to a depth of fully 20 feet at the crest of the moraine. Between the Miami Canal and the State line rock appears at intervals along St. Marys River, but at Rockford a well passed through 130 feet of drift, mainly till, while near that village more than 300 feet of drift is reported by Bownocker. At Enterprise (Ohio City) north of Rockford on the inner slope of the moraine the drift is about 60 feet in thickness. In the southwestern part of Van Wert County wells along the crest of the moraine north of Willshire pass through 70 to 100 feet of drift. Several exposures of rock occur between Willshire, Ohio, and Decatur, Ind., along the St. Marys River, at a level 60 to 75 feet below the crest of the moraine.

[1] Geology of Ohio, Vol. I, 1873, p. 547.

The only wells, so far as ascertained, which reach the bottom of the drift in the Indiana portion of the moraine are in the vicinity of Fort Wayne. A gas-well boring made near the Pittsburg, Fort Wayne and Chicago Railroad, 2 miles east of the court-house, penetrated 100 feet of drift. The driller described it as being mainly blue till in the upper half, but having alternations of till with sand and gravel in the lower half, the till beds being 5 to 6 feet and the sand and gravel beds somewhat thicker. Seven borings made in Fort Wayne and vicinity show a range from $62\frac{1}{2}$ to 123 feet in the thickness of the drift. The public water supply is partly from wells in the drift at depths of 40 to 60 feet and partly from wells in rock at 250 to 450 feet.

At New Haven, just east of the moraine near the head of the old lake outlet, a prospect boring for gas struck rock at about 50 feet below the bed of the Maumee at that point, the amount of drift being 69 feet.

The thickness of the drift along the crest of the moraine east and southeast from Decatur may be about the same as its height above the rock outcrops at and above Decatur (60 to 75 feet), though no records were obtained in that part of the moraine of wells sufficiently deep to reach rock.

Frank Williams, a well driller residing at Avilla, Ind., has made several deep wells near Maples, in Allen County, which penetrated till 70 or 80 feet, and at this depth entered a bed of bowlders which, he thinks, has a definite horizon near the base of the till, for few bowlders are encountered at a lesser depth in the wells.

From Fort Wayne northeastward the drift increases in thickness to 200 feet or more, as shown by deep wells. A well 198 feet deep, on the farm of Christian Hirsch, about 1 mile southeast of Spencerville, in Dekalb County, Ind., does not reach the bottom of the drift. It passes through the following beds:

Section of Hirsch well, near Spencerville, Ind.

	Feet.
Yellow till	8–10
Blue till	50–60
Sand, about	120
Cemented gravel	9
Total	198

A dozen or more wells in the neighborhood penetrate 60 to 70 feet of till and obtain water in the sand and gravel which underlie it. A well at

Byron Hadsell's, near St. Joe, and about 10 rods east of St. Joseph River, is 110 feet in depth. It encountered nothing but sand and gravel. This well is outside the moraine, otherwise it might have penetrated some till.

From the foregoing sections it is apparent that the upper portion of the drift is mainly till, while the lower portion, so far as discovered, is more largely sand and gravel.

OUTER BORDER PHENOMENA.

The portion of the Fort Wayne moraine south of Lake Erie stands so near the divide between the Lake Erie and the Ohio drainage that the glacial waters appear to have found a ready escape into tributaries of the Ohio.

There is likely to have been a small lake in the Cuyahoga Valley discharging southward past the "Akron Summit" to the Tuscarawas, at an altitude of about 965 to 970 feet.

The Sandusky drainage basin also is likely to have had a small lake in the southern portion discharging at first southward to the Scioto through the "Tymochtee Pass," at an altitude about 910 feet above tide. The discharge was probably changed to a westward outlet when the ice front had receded a little from the moraine and offered a lower line of escape. This lake may have received the glacial waters from points on the ice margin as far east as the head of Brokensword Creek. The writer's studies in that region were rather hurried, and the presence of the lake is inferred on theoretical grounds alone, but more detailed studies ought to bring to light features that will prove its existence.

From Dunkirk, Ohio, to Fort Wayne, Ind., the glacial drainage appears to have followed the border of the ice sheet westward in a current inferred to have been sluggish from the fact that the portions of the valleys of Ottawa River (or Hog Creek) and St. Marys River which follow the outer border of the Fort Wayne moraine are not characterized by gravel and sand deposits, such as should accompany a good current. There is a thin deposit of silt on the surface of the plains bordering these valleys, ranging in depth from a few inches to several feet, which seems referable to the flooding of the plains by sluggish waters.

The northwestern limb of this moraine being followed somewhat closely by the St. Joseph River from the Michigan-Ohio line to Fort Wayne, Ind.,

A. GRAVEL PIT AT FORT WAYNE, IND.

B. NEAR VIEW OF PIT SHOWN IN *A.*

the glacial waters would naturally find escape down that valley to its junction with the St. Marys, and thence pass southwestward through the Lake Maumee outlet to the Wabash River. There is a belt of gravel along the St. Joseph Valley which is shown by well sections to have great depth and to pass under the till of the Fort Wayne moraine. It is probable, therefore, that only the surface portion, including perhaps that standing above the level of the present stream, is to be correlated with the Fort Wayne moraine.

In the west part of Fort Wayne there are gravel deposits along the outer border of the Fort Wayne moraine, occupying the interval between the moraine and the St. Marys River. They seem, however, not to have been deposited by direct outwash from the part of the moraine which they border, but seem instead to have been brought in from the north by a stream flowing down the St. Joseph Valley. This interpretation was made by Taylor prior to the writer's visit, and seems well sustained by the bedding of the gravel. The gravel, as shown in Pl. XVI, presents beds with a sharp southward dip, and these are overlain by horizontal beds that appear also to have been produced by a southward-moving stream. The excavations, only a part of which are shown in these photographs, have exposed several acres of the gravel, and there is throughout the excavations evidence of the southward movement of the depositing waters. The course of St. Marys River in its passage through these gravel deposits is northward, or the reverse of the course of the depositing waters. It is probable that the gravel was deposited while the ice sheet still occupied the Fort Wayne moraine, but the stream appears to have had its rise some distance up the St. Joseph Valley. As above noted, the valley carries large amounts of gravel of similar character to that under discussion. This gravel near Fort Wayne is capped by several feet of sand, which in places has been drifted into dunes. The sand may have been deposited by the waters of Lake Maumee, for it extends westward some distance down the lake outlet.

INNER BORDER PHENOMENA.

On the inner slope of the moraine there is a till plain which descends gradually to the upper beach of Lake Maumee. The descent continues past this beach line to the valleys of Blanchard and Tiffin rivers, thus repeating the drainage phenomena of the inner slope of earlier moraines than

the Fort Wayne. On this plain the amount of undulation is very slight, even in the district outside the beach, while on the portion inside or below it the waves have smoothed the surface to such a degree that scarcely a discernible undulation remains.

The drift on this plain is thinner, on the whole, than on the moraine, and its thickness varies, as does that beneath the moraine, there being a thinner sheet in the region south of the Maumee than north of that stream. From Findlay, Ohio, westward to the State line the general thickness scarcely exceeds 20 feet. In the Indiana portion of the plain the thickness is 40 to 60 feet, while in northwestern Ohio it is fully 100 feet.

Aside from thin deposits made by the glacial lake, which to some extent cover the surface of this plain, the drift is mainly till. An occasional well, however, penetrates considerable sand and gravel. Thus at Bryan the drillers report a thickness of about 60 feet of quicksand, or more than one-third of the drift section.

In the vicinity of Auglaize River, from near Ottawa to its mouth, there are deposits of yellow clay several feet in thickness in which pebbles are very rare. Similar deposits have been reported by Winchell to occur along the Maumee Valley. They are probably due to the lake occupancy of that region which followed the glaciation, but the precise mode or modes of deposition can not be stated. The fineness of material distinguishes these deposits from the gravel and sand of the beach lines of the old lake bottom.

The discussion of the beach lines which traverse this plain and of the southwestward outlet of Lake Maumee follows the description ot the Defiance and other moraines, with which they are correlated, a knowledge of the moraines being necessary to a proper understanding of the beaches or lake features.

STRIÆ.

Several observations of striæ in the district lying between the Fort Wayne and Defiance moraines are reported by Winchell and others by Gilbert. Their bearing, as shown by the following list, varies from southwest to nearly due south.

List of striæ observed between the Fort Wayne and Defiance moraines in western Ohio.

Location.	Bearing.	Observer.
Near Upper Sandusky	S. 5° W	N. H. Winchell.
Near Marseilles	S. 10° E' to S. 10° W	N. H. Winchell.
Near Carey	S. 20° W	N. H. Winchell.
Findlay, Hancock County	S. 40°—45° W	N. H. Winchell.
Section 20, Blanchard Township, Putnam County	S. 28° W	N. H. Winchell.
Section 13, Sugar Creek Township, Putnam County	S. 50° W	N. H. Winchell.
Section 15, Amanda Township, Allen County	S. 35° W	N. H. Winchell.
Lima, Allen County	S. 35° W	G. K. Gilbert.
Section 31, Auglaize Township, Paulding County	S. 48° W	N. H. Winchell.
Near Junction, Paulding County	S. 45° W	G. K. Gilbert.
Middlepoint, Van Wert County	S. 15° W	G. K. Gilbert.

BLANCHARD OR DEFIANCE MORAINE.

This moraine, like the one outside of it, has received two names—one, Blanchard, from a stream whose course it governs, and the other, Defiance, from the principal city in the line of the moraine. While the former has priority in use, the latter seems to be supplanting it, for it is commonly referred to among glacialists as the Defiance moraine. Its course from Findlay, Ohio, west and north to the Michigan line, was determined by Gilbert about 1870. The writer's studies have brought to light the eastward continuation from Findlay.

DISTRIBUTION.

The Defiance moraine, as indicated in Pls. II and XIII, follows the western border of the great interlobate moraine which occupies the uplands west of Grand River Basin in Ohio, and is in places distinct from the remainder of the morainic belt. From near Chardon it passes southwestward between Chagrin Falls and Twinsburg, and comes to the Cuyahoga Valley just below Peninsula. Thence it continues southwestward past Richfield, near which village it separates into two members.

The outer or main member is closely associated with the St. Marys and Wabash moraines to the vicinity of Lodi, but farther west it is entirely distinct from them. The inner member passes through Medina and crosses Black River about 5 miles below Lodi, beyond which it is traceable only about 15 miles, its western terminus being near Rochester.

The outer or main ridge leads from Lodi in a course slightly west

of north through New London, and crosses Vermilion River just below the junction of the two forks. A spur from the moraine extends north 2 or 3 miles along the east side of the river valley. From Vermilion River the moraine bears south of west to Chicago Junction, but a spur extends north several miles along Huron River, reaching the old beach south of Norwalk. The moraine curves to the north of west at Chicago Junction and passes through Attica to Republic. It then turns abruptly southwestward, following the north side of Honey Creek to Melmore, where it crosses the creek and soon comes to the valley of Sandusky River. It crosses the river below Mexico and follows up its northwest bluff to McCutcheonville. It then leads westward through Alveda to the bend of Blanchard River a few miles east of Findlay, from which point west and north it was traced by Gilbert. For about 15 miles its course is south of west along the north side of Blanchard River through Findlay to the vicinity of Gilboa. It there turns northwestward, leaves the river, and takes a nearly direct course to Defiance, its outer border through much of the way being followed by Powell Creek, a small tributary of the Auglaize River. Its course north of the Maumee, as outlined by Gilbert, is east of north through northeastern Defiance, northwestern Henry, and central Fulton counties, its crest constituting the divide between Tiffin River and eastward-flowing tributaries of the Maumee. Its course in Michigan was outlined by Gilbert as far as Adrian, that city being at the western border of the moraine. The writer has continued the tracing in Michigan to the Imlay outlet north of Imlay, Mich., but the discussion of the Michigan portion is reserved for another report, now in preparation.

It is a fact worthy of note that with the single exception of the Maumee River no stream crosses this moraine between Findlay and the Ohio-Michigan line, a distance of fully 75 miles. The streams on its outer border flow parallel with it, and away from Lake Erie, until they enter the Maumee, then their line of discharge becomes nearly direct into the lake. The streams on its inner border flow directly toward Lake Erie.

RELIEF.

The breadth of the moraine is seldom less than 2 miles, and is in places 4 miles or more. It is like a broad wave whose crest stands 20 to 50 feet above the border of the plain outside it. It falls away gently on the inner

face, the descent being barely perceptible to the eye, but its outer face has a more rapid descent. On portions of the inner slope the lake waves have cut benches or accumulated gravelly ridges which interrupt and modify the original smoothness of the slope. The outer border has definite relief throughout the curve in western Ohio and as far east as Lodi, beyond which it is so closely combined with the St. Marys moraine as to be difficult of separation. The weak inner member developed between Richfield and Rochester has a relief of but 10 to 20 feet, but as it is usually only one-half mile or so in width it is very distinct.

RANGE IN ALTITUDE.

The altitude of the crest of this moraine in the part traced by Gilbert west from Findlay declines from about 850 feet on the meridian of Findlay to less than 750 feet at the bluffs of the Maumee, but rises north from the Maumee to a height of nearly 850 feet near Adrian, Mich. The altitudes along the portion east from Findlay are set forth in the accompanying table

Altitudes along the Defiance moraine between Medina and Findlay, Ohio.

Station.	Authority.	Altitude above tide.
		Feet.
West of Medina	Northern Ohio R. R.	1,103
Chatham Center, 1 mile north of	Barometric	1,120
Lodi, moraine near	Ohio Geological Survey	933
Lodi station	Cleveland, Lorain and Wheeling R. R	903
Nova, 2 miles northeast of	Preliminary Survey Northern Ohio R. R.	1,182
Near New London	Barometric	1,050
Near Chicago Junction	Barometric	950
Attica	Baltimore and Ohio R. R	963
Near Rockaway	Barometric	900
Sandusky River bluff	Barometric	830
Alvada	Columbus, Hocking Valley and Toledo R. R.	851
North of Findlay	Barometric	850

TOPOGRAPHY.

In its surface contours the Defiance moraine presents more variation than any of the minor moraines already discussed. The portion which was deposited above the level of Lake Maumee, and which may be designated

the land-laid portion, presents all the variations displayed by the moraines outside of it, and has more prominent spurs on its inner or north border. The portion which was deposited below the level of Lake Maumee, and which may be designated the water-laid portion, presents a smooth, somewhat flattened surface, decidedly in contrast with the land-laid portion.

The detailed description which follows begins at the eastern end at the interlobate tract west of Grand River Basin and proceeds westward along the moraine.

The portion of the morainic series east of the Cuyahoga does not exhibit either a single well-defined crest or a series of such crests which can be correlated with the several distinct belts farther west. Instead, it forms a billowy sea of swells and sags, knobs and basins. It is characterized on its eastern border by numerous sharp knolls and winding ridges, 15 to 50 feet in height, with hummocky slopes, among which are occasional basins. In places the basins form a chain, connected by narrow sloughs, but quite as often they are isolated, being either without an outlet or having but a narrow one. The basins just referred to are small, covering but a few acres each. There are also a few large basins covering a square mile or more, some of which contain lakelets. Such are Pundesons Pond, north of South Newberry, and smaller lakes east of that village, and the Twin Lakes near Earlville, and Turtle Lake and Silver Lake north of Cuyahoga Falls. These lakes appear to occupy shallow basins, and nearly all of them have outlets. They are fed by springs from the bordering gravel knolls.

The western or inner portion of the morainic system, which includes, perhaps, all that should be correlated with the Defiance moraine, is characterized by a gentle swell-and-sag topography with an occasional development of sharp knolls and a few small lakes. There is a somewhat distinct belt of sharp knolls lying slightly within (northwest of) the main morainic belt which is thought to be of the date of the Defiance moraine. It constitutes a nearly continuous series of knolls covering a belt a mile or less in width, which passes from near Fowlers Mills in a southwesterly course just south of Russell Center and Solon Center to the valley of Tinkers Creek at South Solon, beyond which its continuation was not so definitely worked out. Its knolls are 20 to 50 feet in height, the most prominent ones being in the vicinity of South Solon in Tinkers Creek Valley. In places where sharp knolls are wanting it presents gentle swells and a well-defined relief of 15 to 30 feet above the immediate outer border.

Along the bluffs of the Cuyahoga, from near Peninsula southward to the bend of the river, the moraine is characterized by lower swells than on the higher lands a short distance back from the river. The bluffs bordering the stream are about 250 feet high, but they do not represent the height of the uplands, there being a rise of nearly 250 feet more to the brow of the escarpments of Carboniferous conglomerate which border the valley at a distance of 1 to 3 miles from the stream. The tract along the valley between these escarpments bears resemblance to a terrace in its nearly uniform altitude, but it is dotted with low drift swells of morainic type. It is probable that the valley was filled with drift about to this height while the ice overhung it, and the inner valley, 250 feet in depth, has been excavated since the ice sheet withdrew. Between this stream and Medina there are few drift knolls worthy of note; but west of Medina, in the southern part of York Township, Medina County, are numerous drift knolls and ridges which in places are definite enough to admit of description. The inner ridge lies just south of York Center, a very level tract extending for several miles north from that village. The ridge trends northeast to southwest and rises abruptly 20 to 25 feet above the plain northwest of it. A second ridge, about one-fourth mile from this, on the southeast, rises 10 to 20 feet higher still. Near the south line of York Township is another drift ridge 20 feet or more in height, which has an east-to-west trend. The interval between these ridges is well filled with drift knolls about 10 feet high. This system of ridges and knolls continues in a course south of west across southeastern Litchfield Township, its principal ridge touching the southeast corner of that township. There are scattering knolls outside this main ridge in the northern part of Lafayette Township. In Chatham Township, also, the moraine is separable into three distinct ridges. The outer one occupies the eastern part of the township and trends north-northeast to south-southwest. It consists of a nearly continuous chain of knolls 10 to 20 feet high, on each side of which there are scattering knolls. It lies on the slope east of the southward-flowing portion of East Black River. The middle ridge occupies the central portion of the township, passing from north to south entirely across it. It lies west of East Black River, and constitutes the barrier which caused the stream to take a southward course in this township. It is about a half mile in width, and is a smooth ridge with scarcely any knolls and basins along it. However, about a mile south of Chatham Center, and 60 rods west of the Center road, a basin several feet deep, and

just north of it a sharp knoll 12 to 15 feet high, were noted. The ridge continues south to Lodi, in Harrisville Township, where it unites with the outer one. The inner ridge crosses the northwest corner of Chatham Township in a northeast-to-southwest course, being combined with the middle ridge in the north part of the township, but entirely distinct from it throughout its course toward the west.

The inner one of the ridges above noted is developed as a distinct ridge for a distance of 20 miles farther west, and its general course was outlined in connection with the distribution of the moraine. It has a width of only one-fourth to one-half mile, but stands 10 to 25 feet above bordering tracts. Between it and the main Defiance moraine there is a nearly plane tract rising toward that moraine, whose main crest from Black River westward lies 2 to 5 miles south of this inner ridge. The ridge may be traced without difficulty as far west as the bend of Black River in southwestern Brighton Township. West of this stream there is no well-defined ridge, but drift knolls are quite numerous for a short distance, when the morainic topography disappears, there being a nearly plane tract both to the north and west.

Returning to the main ridge at Lodi, we find a sharply rolling belt standing 15 to 30 feet above the Harrisville Marsh, which borders it on the south. There are shallow basins both on the crest and slopes. Some of them contain boggy bottoms but none were observed to hold lakelets. The moraine crosses a western tributary of East Black River, 2 miles southwest of Lodi. It then curves to a course north of west and follows the north side of that stream to its source, there reaching a culminating point with an altitude about 1,180 feet above tide, from which it descends southward to the Vermilion River. It consists throughout this portion of its course of a single ridge with sharp crest, on the slopes of which there are numerous gentle swells 5 to 15 feet in height. It is more conspicuous by its relief than by its knolls or morainic contours, the relief being 20 to 40 feet and rather abrupt. The inner slope has but gentle undulations as far west as the meridian of New London, beyond which it is dotted with sharper drift knolls, which become more and more numerous upon approaching Vermilion River, until at the east bluff of the river they constitute a very sharply morainic belt which extends north a few miles as a spur from the moraine. The northern end of the spur is about a mile north of the corners of Hartland, Clarksfield, New London, and Fitchville townships, Huron County, where

it terminates abruptly with sharp knolls 20 feet or more in height. For $2\frac{1}{2}$ miles south from this place the spur consists only of a chain of scattering knolls, about one for every one-fourth mile, which follow somewhat closely the range line between New London and Fitchville townships. The knolls are conical hillocks 10 to 30 feet in height, rising abruptly from the plain which they occupy. The spur then assumes greater proportions, and contains numerous basins, 6 to 10 feet or more in depth, and winding ridges as well as conical hillocks, the whole surface being undulatory. About a mile to the south it joins the main ridge of the moraine which, in passing this spur, still maintains its distinct east-to-west trend.

Westward from Vermilion River the moraine for about 7 miles consists of a single main ridge. Its crest is not so continuous nor of so uniform height as east from that stream, and its slopes are dotted by larger knolls, some knolls being 30 feet or more in height, while knolls 10 to 20 feet high are numerous. Basins occur but are not so deep nor so numerous as in the spur east of Vermilion River. The breadth of this portion of the moraine is about 2 miles. North from it the surface soon becomes quite plane.

In eastern Fairfield Township and in Greenfield and Peru townships, Huron County, in the districts embraced between the east and west branches of Huron River, there is another spur running northward 7 or 8 miles from the main ridge of the moraine. The moraine here embraces nearly all the known phases of morainic topography, a portion of it being a gently undulating swell-and-sag tract, while a larger portion is characterized by sharp knobs and basins; esker ridges also occur in combination with the knolls and basins, and near the northern end of the spur, where the knolls are low and infrequent, numerous basins occur, while along the south border of the spur there is the till ridge which forms the moraine proper. The southern portion of Greenfield Township presents a swell-and-sag topography, the swells being 10 to 25 feet in height. The northern portion of this township and adjoining portions of Fairfield and Peru present a sharp knob-and-basin topography, the knobs being 10 to 50 feet in height while the basins range from a foot or two up to 20 feet or more in depth, some of the deepest basins occupying an area of but 1 to 2 acres.

The principal esker ridge within this spur lies along the "ridge road" leading south from Norwalk through western Bronson and western Fairfield townships. It extends from the southern part of Bronson Township

southward about to the east-to-west center road in Fairfield Township, a distance of 3 miles. Its height ranges from 10 up to 50 feet, or even more. Its breadth, including slopes, is 75 to 125 yards. It presents, therefore, very abrupt slopes. There are occasional short spurs running out from it, and at its southern end there is a plexus of sharp, esker-like ridges, 40 to 50 feet high, inclosing basins 20 to 30 feet in depth, the system occupying a breadth of one-fourth mile or more. It is bordered on each side throughout its entire length by the knolls of the morainic spur, and its surface in places has hummocks of drift plastered onto it which, when numerous, cause it to resemble a moraine more nearly than an esker. These hummocks on the esker ridge contain poorly assorted material together with small amounts of till, features which indicate glacial deposition rather than fluvial. The features suggest that the material forming this esker was laid down by a stream flowing beneath the ice sheet, and that the englacial material was subsequently left upon it in irregular deposits as the ice sheet disappeared. In Greenfield Township, in the vicinity of the middle branch of Huron River, there are short esker ridges one-half mile or less in width, having either a north-to-south or a northeast-to-southwest trend.

North of Macksville, among the low swells, are basins, which range in depth from 8 to 15 feet. Topography of this character extends to the upper beach of Lake Maumee, and probably extended slightly farther north before the beach was formed, there being in northern Peru Township occasional basins just north of the beach line; they do not, however, extend a mile beyond the beach. The knolls, if present in that district, have been entirely obliterated by the lake waves, so that with the exception of these basins the morainic features appear to terminate at the beach line. In the western part of Peru Township the beach follows the northwest bluff of Huron River and has sandy knolls 10 to 20 feet in height associated with it. It is possible that these knolls are of glacial origin, though it seems probable, from their restriction to the borders of the beach, that they received their sand from the glacial lake. The cause for the development of this prominent spur has not been determined.

The main ridge continues westward past the southern end of this spur, its crest being about a mile south of Chicago Junction. It is here decidedly billowy, with numerous swells 10 to 20 feet high, but within a mile west of the meridian of Chicago Junction it loses its sharply morainic expression

and consists of gentle swells rising 10 to 15 feet in a distance of 30 to 40 rods. The whole surface is, however, gently undulating and presents a decided contrast to the flat tracts bordering the moraine on the north and on the south. For 3 or 4 miles the moraine is low and its expression feeble. It then assumes the form of a sharp main ridge, standing 20 to 30 feet above the plain south of it, on which there are numerous low swells 10 feet or less in height and an occasional larger one 15 to 20 feet in height; basins also are not infrequent. The breadth of the ridge, including slopes, is scarcely a mile. This sharply ridged phase continues to the vicinity of Republic, where the moraine expands to a width of 2 or 3 miles, and curves from a course north of west to one nearly southwest. In this broad portion there are ridges forming the southern border of the moraine, north from which are loosely connected knolls and low short ridges of drift forming a rolling or billowy surface. The oscillations are in places 25 or 30 feet in 300 to 400 yards. The widening of the moraine here has the form of a slight spur.

At the curving portion of the moraine, south of Republic, there is a double ridge, each member of which trends east-northeast to west-southwest, but only the inner one continues far to the southwest. This ridge leads down to the Sandusky Valley, following the northwest side of Honey Creek to Melmore, where it crosses the stream and passes southwestward to the Sandusky River. On this slope, between the creek and river, it presents only low swells, seldom exceeding 5 feet in height, and occasional shallow basins. There is a well-defined ridge trending east-northeast to west-southwest, lying near the Melmore and Mexico road in sections 33 and 32, Eden Township, which constitutes the outer border of the moraine. North of it for a mile or more is an undulating tract, points on which rise slightly above the level of the outer ridge.

West of the Sandusky River the moraine has stronger expression than it has on the east side of that stream, its highest points, where crossed by the Tiffin and McCutcheonville road, standing 40 to 50 feet above the village of McCutcheonville and about 75 feet above the river. It consists here of a series of short ridges with east-to-west trend and numerous knolls 10 to 15 feet high covering 3 to 5 acres or more each. There are a few basins on its outer slope.

From the Sandusky River westward, past Findlay to western Hancock County, there is a nearly continuous ridge, on whose crest and slopes are

gentle swells 10 feet or less in height, and shallow, saucer-like depressions. Similar swells and basins characterize nearly the whole of the tract lying between the morainic crest and the upper beach of Lake Maumee, about 6 to 8 miles to the north.

Near the county line just referred to the crest becomes ill defined and the moraine consists of a series of small, sharp knolls with abrupt slopes, among which are numerous basins. These knolls and basins, small though they are (seldom occupying an acre each), present all the characteristic features of the knob-and-basin topography of a kettle moraine. The knolls, however, rarely exceed 10 feet in height, whereas in the strongly developed portions of kettle moraines they rise abruptly, in some cases to a height of 100 feet. This phase seems to mark the transition from the land-laid to the water-laid portion, and is developed for a distance of only 10 or 12 miles.

About 3 miles northwest of Leipsic the moraine is crossed by the upper beach of Lake Maumee, and from there to the Maumee River and thence northward nearly to Wauseon, Ohio, it presents a very smooth surface. To the unaided eye this portion can not be readily distinguished from the bordering plains. Indeed, there are few places within the region under discussion where the drift surface is so nearly featureless. Yet this part of the Defiance moraine has sufficient relief to control drainage to a remarkable degree and to cause the Belmore beach to extend out nearly to the Maumee River, as indicated on Pl. XXIV. This smoothness of the moraine is apparently due to its having been laid down in water rather than to subsequent wave action. The wave work shown in the beaches and cut banks of that region is evidently inadequate to produce so marked a change as the moraine presents in passing from the land-laid to the water-laid portion. The studies carried on by Taylor in eastern Michigan and in the Province of Ontario have brought to light several water-laid moraines, which, like this portion of the Defiance moraine, are known to be present from their connections with well-defined land-laid moraines and from their influence upon drainage, but which are with difficulty detected by the eye.

From the vicinity of Wauseon northward to the Michigan line there is a tract similar to that near Leipsic which connects the land-laid and the water-laid parts of the moraine, though it is more sandy. There are a few

low till swells 5 to 10 feet high, and with them sandy knolls and ridges, some of which are 20 to 25 feet in height. This part of the moraine is known to have been only partly submerged, for portions of it rise 20 to 30 feet above the level of the upper beach of Lake Maumee, yet the sand has been deposited on the highest points. There has probably been some transportation of the sand by wind after the withdrawal of the ice sheet, but some of the sand knolls appear to have been formed like the till knolls in connection with glaciation. This seems to be the case where knolls of sand are isolated, and separated from other sand deposits by wide areas with scarcely a trace of sand, as often occurs in that part of the moraine.

Upon continuing north into Michigan a few miles the typical land-laid moraine appears, with a sharply outlined crest and swell-and-sag topography, similar to that found near Findlay, Ohio. The description of the Michigan portion of the moraine will, however, be deferred to a later report.

STRUCTURE OF THE DRIFT.

The Defiance moraine, like the moraines which lie outside of it, is composed very largely of till in which there is a liberal admixture of small stones, but surface bowlders and large stones are comparatively rare. The water-laid part seems to be a little more compact than the land-laid part, but the contrast is not striking. The water-laid part carries remarkably little surface sand, much of its surface being a black, mucky clay. The little sand and gravel which occurs is mainly confined to the Belmore beach and its immediate borders.

As already noted, sand knolls are a conspicuous feature from near Wauseon northward to the Michigan line. There are also a few in the tract near Leipsic, Ohio, that connects the land-laid with the water-laid part of the moraine. These are often composed of clear sand, but in some cases a few pebbles are present. The sand is somewhat calcareous at depths of several feet from the surface, but the surface portion seems to be thoroughly leached. In the portion near Leipsic some interesting variations are displayed; in one knoll only a fine sand may be present, while its neighbors are composed of clay, or a portion of a knoll may be composed of sand and the remainder of clay, the whole being molded into a symmetrical knoll, like the different kinds of material in a kame. A few knolls contain pockets of gravel, but coarse material is rather rare. These abrupt

variations are perhaps to be expected in the part of the moraine which was formed near the lake level.

In the land-laid part of the moraine from near Findlay eastward occasional sharp gravelly knolls occur, and also a few short esker ridges, as already indicated, but they do not constitute a conspicuous feature.

The surface bowlders, as in other moraines of this region, are chiefly crystalline rocks of Canadian derivation, but Paleozoic rocks are also represented. Some of the rocks and minerals are of such restricted outcrop that their sources may be determined, notably the red jasper conglomerates, copper nuggets, and certain limestones.

Red jasper conglomerates have been found on the spur of the Defiance moraine south of Norwalk, and copper near Medina, both of which are thought to indicate that there has been an ice movement in a course east of south from the north shore of Georgian Bay and the eastern end of Lake Superior. This being true, the movement is out of harmony with the later movements of the ice sheet in northern Ohio, which, as shown by moraines and striæ, were southwestward. A fine specimen of the red jasper conglomerate is to be seen in the yard in front of F. Parrott's residence, in the northwest part of Fairfield Township, about 8 miles south of Norwalk. It was found by Mr. Parrott near the line of Peru and Bronson townships, a mile or more south of Macksville. It is 3 or 4 feet in diameter and well rounded. One-half is an almost solid mass of pebbles, whose size ranges from one-half inch up to 2 inches or more. The majority are semitransparent quartz, but red and blue jasper pebbles are not rare. The other half of the rock is nearly free from pebbles, being a coarse-grained quartzite with a faint pink tinge. The pebbles are so firmly cemented that they are in some cases more easily fractured than torn loose from their matrix. Bowlders of this class are not rare over the portion of Ohio lying west of a line connecting Brownhelm, Norwalk, and Mansfield, but are very rare farther east.

The limestone bowlders in Northampton Township, Summit County, which Newberry thinks were derived from the islands of Lake Erie[1] lie in this moraine, but those observed near Talmadge lie in an earlier moraine It is quite probable that these limestones and also the red jasper conglomerates and other bowlders derived from the north or northwest were

[1] Geology of Ohio, Vol. I, 1873, p. 206.

brought in before this moraine was formed and were then taken up and redeposited with the moraine.

The following detailed account of well sections and other exposures of the drift begins in Geauga County near the great interlobate moraine and follows the Defiance moraine westward.

Mr. Ashcroft's well, on elevated land in Munson Township, Geauga County, penetrated 20 feet of till without reaching rock. A knoll near by rises 20 feet above the well mouth.

At Leach's grocery, in southern Newberry Township, a well struck rock at 50 feet. It is on comparatively low ground, 150 to 175 feet below sandstone hills north of it. On these hills the drift seldom exceeds 30 feet in depth.

At Mrs. Reed's, 2 miles west of South Newberry, on ground slightly higher than that in the village, a well 159 feet deep did not reach rock. It was mainly through sand, but there was a soapy clay at bottom. Bowlders were encountered at 40 to 42 feet.

At William McLaughlin's, 2 miles west of South Newberry and less than one-half mile from Mrs. Reed's, a well penetrated a large amount of blue till, the only thick bed of sand and gravel being in the lower 25 feet. Rock was struck at 162 feet.

About a mile west of McLaughlin's, on ground but little lower, rock is exposed in shallow ravines, and southward from there along Bridge Creek, in Auburn Township, rock is exposed to a height of 25 feet above the creek. Immediately west of this creek, on ground but a few feet higher, wells 70 to 80 feet in depth do not reach rock.

Near Auburn Center ravines 30 to 40 feet deep do not expose rock. The drift in knolls near Auburn Center contains much gravel, but below the level of the base of the knolls there appears to be a sheet of till.

In the northwest part of Auburn Township G. A. Richards has a well on comparatively low ground which does not strike rock at a depth of 65 feet.

A well at Oscar Niece's, in Brainbridge Township, southwestern Geauga County, is reported by the well driller, R. A. Dayton, of Burton, Ohio, to have penetrated 115 feet of drift. A well 3 miles west of Bainbridge Center, near the line of Geauga and Cuyahoga counties (owner's name not known), also reported by R. A. Dayton, penetrates about 200 feet of drift.

At Asahel Chamberlin's, 3 miles north of Twinsburg, a well struck rock at 55 feet, as reported by the well driller, E. B. Center. At C. H. Cramer's, one-fourth mile north of Chamberlin's, the drift is 80 feet. At S. Hales, across the street from Cramer's, the drift is also 80 feet. At Mrs. Maloney's, 2½ miles north of Twinsburg, the drift is 60 feet.

At George Haskell's, in the southeastern part of Solon Township, Cuyahoga County, a well 75 feet deep does not strike rock. At James Aiken's, also in the southeastern part of Solon Township, a well passed through 140 feet of drift. At Frank Baldwin's, near Aiken's, the drift is about 125 feet. In the last seven wells mentioned the drift is mainly till, though in some of them the drillers were troubled by beds of quicksand.

At Twinsburg, in the valley of Tinkers Creek, a well at Albert Chapman's, 108 feet deep, does not reach rock. It is mainly through sand. At William Center's, 3 miles northwest of Twinsburg, a well entered rock at 40 feet, and at E. B. Center's, one-half mile west, on ground with about the same altitude, rock is struck at 14 feet. For 2 miles north or south from E. B. Center's many wells on the high ground reach rock at 14 to 25 feet.

At Macedonia, Leroy Foster's well penetrated 80 feet of drift, largely sand. At B. A. Robinett's, one-half mile northwest of Macedonia, a well struck rock at 40 feet, and a short distance north of there rock ledges rise considerably above the level of Macedonia station.

In Aurora Township, Portage County, exposures along ravines show 30 to 40 feet of till with scarcely any assorted material, and no outcrops of rock were noted.

In Streetsboro Township the moraine is composed of till in the central and western portions and gravelly knolls in the eastern. Several wells show the drift to be rather thick. One, a mile north of Streetsboro Center, at Mrs. Russell's, struck rock at 115 feet. At Streetsboro Center, N. D. Peck's well, 74 feet deep, did not reach rock. At Samuel Barker's, 1½ miles south of Streetsboro Center, a well 146 feet deep strikes no rock. The upper 100 feet was till, the remainder gravel. At H. V. Crowley's, one-half mile farther south, a well 252 feet deep did not reach rock. It passed through much sand and gravel. The well mouth is about 30 feet lower than at Barker's, or about 1,125 feet above tide. About 2 miles southeast from Mr. Crowley's, on the east side of East Twin Lake, is a well 300 feet

deep which did not reach rock. It is on Mrs. James Haymaker's farm. The altitude of the well mouth is about 1,100 feet above tide. The Cleveland and Canton Railway has driven spiles in the borders of a swampy tract between Streetsboro station and Streetsboro Corners to a depth of 127 feet without reaching rock. The above sections indicate a deep valley between Streetsboro and Kent in what is now a gently undulatory district but little lower than the sandstone hills. No definite knowledge as to its preglacial course and connections was obtained, since the region is so heavily covered with drift in all directions as to obscure the preglacial topography.

Newberry reports a well in the valley of Cuyahoga River, near the line of Cuyahoga and Summit counties, that struck rock at 220 feet below the level of the stream and about 175 feet below the level of the surface of Lake Erie.[1] Several borings in Cleveland show a rock floor much lower,[2] the lowest level being nearly 500 feet below Lake Erie, or not more than 100 feet above tide.

Within the city of Medina a range in the thickness of the drift from zero up to 60 feet was noted, the greatest depth reported being in a well for the city at the northwest corner of the public square. The altitude is about 30 feet greater at this well than at rock outcrops in the southwest part of the city.

In Chatham Center a well at E. Talbott's, 42 feet deep, obtains water from a gravel bed beneath till. A well at the crossroads in this village, 56 feet in depth, did not reach rock. On Mr. Sanford's farm, 1½ miles south of Chatham Center, a well was made many years ago by Mr. Packard which was still in the drift at a depth of 50 feet. These wells are all near the crest of the morainic ridge that follows the west side of East Black River.

At Lodi rock is exposed in the low ground near Black River and is reported to be struck at slight depth beneath the Harrisville Marsh, south of that village; but a deep channel has been discovered west of Lodi in the lowland tract connecting Black River and Killbuck Creek, the drift there being about 200 feet in depth.

At the village of Homerville, which stands just south of the Defiance

[1] Geology of Ohio, Vol. I, p. 205.

[2] Am. Geologist, Vol. XX, pp. 176–181, Pl. XIII. See also Bull. Geol. Soc. America, Vol. VIII, 1897, pp. 7–13.

moraine, rock is struck at 10 to 15 feet. The thickness on the moraine is probably as much greater as its relief above the outer border district—about 30 feet.

At the village of Sullivan, also just south of the moraine, a well at the Sullivan House, 35 feet deep, does not reach rock; and many other wells in that vicinity obtain water from the drift at 25 to 30 feet. Blue till is encountered at about 10 feet and extends to the water vein, which is usually from gravel. On the north slope of the moraine, 3 or 4 miles northwest from Sullivan, there are exposures of rock in the shallow ravines. The thickness of drift along the crest in this vicinity probably averages 50 feet, as it stands fully 30 feet above the bordering plains.

At Nova the town well strikes rock at 25 to 30 feet. This village also is on the plain south of the moraine.

Along the inner till ridge, in Spencer and Huntington townships, rock is struck at 20 to 30 feet, and outcrops are found in shallow ravines. In Spencer Center there is a cutting 15 feet deep, where the ridge is crossed by the Wheeling and Lake Erie Railroad, which shows yellow till from the top nearly to the base, and there blue till sets in. A few rods south is a ravine in which rock appears at a level about 20 feet below the base of the cutting.

In the vicinity of New London the drift is rather thick. Dorr Smith, a well driller, has made several wells in the village which have passed through 95 to 115 feet of drift. Many wells obtain water in gravel below till at 75 to 95 feet. It is Mr. Smith's opinion that there is a buried channel leading from New London northeastward past Wellington, for rock is not struck along this line at so shallow depth as it is on either side of the line. A well at Bushnell Post's, 2 miles north of New London, appears to be in this channel, since it has over 100 feet of drift; and two wells in the southwest corner of Brighton Township, Lorain County, also appear to be in the channel—one at D. S. Stocking's having 98 feet, and the other at C. D. Stocking's 88 feet of drift. In C. D. Stocking's well there is 68 feet of till, beneath which 20 feet of fine sand was penetrated. Near Rochester, about 2 miles southeast of Mr. Stocking's and at about the same altitude, James Horton has a well which struck rock at only 55 feet, and rock is struck in shallow wells a mile or so west of Mr. Stocking's. In Wellington there are several wells which penetrate 90 to 105 feet of drift.

The upper 75 feet is usually a compact till, below which there is a fine sand extending to the rock. About 2 miles northeast of Wellington, at a cheese factory, a well penetrated 91 feet of drift. The channel has been traced no farther northeast. The drift has completely concealed its course, hence it is only by borings that it can be traced. It probably leads into the Lake Erie Basin.

Near Fitchville, where the moraine crosses the Vermilion River, there are exposures of rock. The knolls which constitute the spur along the east side of this stream contain much gravel and sand, while the main moraine in that vicinity is composed largely of till. Gravel probably occurs in the sharpest of the knolls along the main moraine, but no exposures were observed.

The esker ridge in the northwestern part of Fairfield Township presents no deep exposures, but is probably composed, in the main, of gravel and sand. The surface is a poorly assorted material, grading on the one hand into till and on the other into sand and gravel.

There is gravel at slight depth in the northern portion of the spur from Macksville northward, the capping of till being but 5 to 10 feet in thickness. Many of the basins which occur in this region are dry, even when without outlet, a pretty certain indication that they are underlain by gravel and that the till which covers the knolls does not pass underneath the basins. The large knolls in Peru Township, west of Macksville, exhibit a variable structure, there being rapid transitions horizontally from till to gravel and sand. A well 50 feet in depth, at Mr. Ruggles's, on a high point about three-fourths of a mile south of the center of the township, passed through 23 feet of till in its upper portion, the remainder being sand.

Isaac Lafever, a well driller residing at Chicago Junction, states that the drift in that village is 100 to 120 feet in thickness. There is a continuous sheet of till for 60 feet, beneath which is a thin bed of gravel from which some wells derive water. Beneath the gravel is a sandy till, harder and drier than that above. It contains pockets or thin beds of gravel, from which some of the wells obtain water. The well at the Dole House entered rock at 107 feet. In a town well just east of the railway junction gas was found in the drift at a depth of 95 feet. It bubbles up in connection with the water. About 1¼ miles south of Chicago Junction, on the crest of the moraine, there are several wells from which gas is obtained in

the drift at a depth of about 65 feet. They are on the farms of Messrs. Williams, Buzzard, and Courtwright. The wells penetrate till for about 60 feet and then a hard cemented clay for about 5 feet, at which point gas is struck in a bed of sand. The gas when lighted is reported to have blazed to a height of several feet. A well on Samuel Miller's farm, a mile west of Chicago Junction, struck gas at a depth of 64 feet, but water came in soon after the gas was struck, since which time gas has not been observed to escape from the well. A short distance from this well, on the farm of Mr. Franklin, a flowing well was obtained at the base of the drift at a depth of 83 feet; water rises 4 feet above the surface. The well is south of the Baltimore and Ohio Railroad and on ground 10 feet or more below the level of the track.

At Attica station a well made by the railroad just mentioned struck shale at 70 feet. The drift was mainly blue till. A gas-well boring in the village of Attica has about 80 feet of drift. Between Attica and Chicago Junction, along the line of the moraine, there are several wells 40 to 60 feet in depth, which obtain water from gravel beneath the till. A short distance north of Attica limestone rises nearly to the surface and the drift continues thin from there northward as far as the upper beach of Lake Maumee at Bellevue. It is also thin west of Attica compared with its thickness between that village and Chicago Junction, the general thickness along the moraine being less than 50 feet, while on bordering plains it is so thin that ravines 10 to 20 feet in depth reach the rock.

At Melmore there is an exposure of till 40 feet in height in the bluff of Honey Creek, and west from Melmore on Sandusky River there are similar exposures of till.

At Frenchtown, 2 miles west of Berwick, the drift is fully 90 feet thick, and from there west to Alveda, along the line of the moraine, wells penetrate 60 to 80 feet of drift. A short distance south of this portion of the moraine, near Springville, there are limestone ridges which rise above the level of the crest of the moraine. These ridges extend south nearly to Carey, and thence west to Vanlue. The drift is, as a rule, very thin on the plain between the Defiance and Fort Wayne moraines from the Sandusky River westward beyond the meridian of Findlay, its general thickness being but 10 to 20 feet. North of the moraine, also, it is much thinner than along the crest, the general thickness from the Sandusky River westward to the meridian of

Findlay being about 30 feet. North of Findlay the thickness on the crest is about 50 feet, while on the inner slope at Stuartsville it is about 25 feet. In a well at McComb, a few miles to the west, rock is entered at 62 feet.

On the outer border plain from Findlay westward to within 4 miles of Ottawa rock is frequently struck at about the level of Blanchard River, or but 15 to 20 feet below the level of the base of the moraine. On the crest of the moraine north of Gilboa a well at Dr. Newman's residence penetrated 80 feet of drift. It passed through several feet of sandy material, then a few feet of yellowish-brown clay, and entered blue clay at about 16 feet. A well at F. J. Oren's, on the outer face of the moraine, one mile south of Newman's, penetrated 70 feet of drift. It entered a stony clay near the surface and passed through it to a depth of 45 feet. Here a blue sandy clay nearly free from pebbles was struck, which continued about to the rock.

Near Crawfis College, just south of the moraine, a well at Joshua Powell's struck rock at 40 feet. At the railway pumping station, a few rods south and at an altitude 7 or 8 feet lower, rock is struck at 47 feet. At the latter well the material thrown out at the time of digging was mainly a blue sandy clay nearly free from pebbles. There is only about 4 feet of oxidized surface clay at this well, but some wells in that neighborhood penetrated 20 to 25 feet of sand and oxidized clay before striking the blue clay.

At Leipsic a gas-well boring penetrated 78 feet of drift, said to be mainly blue clay. Several wells in the vicinity of West Leipsic struck rock at 90 to 100 feet. After passing through the sandy surface deposits, which are but 10 to 15 feet thick, there is usually an unbroken sheet of blue clay (till) extending to the rock. It is said to contain some pebbles and an occasional bowlder.

At Henry Foltz's residence, 2 miles northwest of West Leipsic and on the highest part of the moraine, rock was struck at 88 feet. There is 8 or 10 feet of sandy surface clay, beneath which is blue clay extending to the rock. Three other wells in the neighborhood of Foltz's strike rock at 88, 95, and 96 feet, respectively. Many wells in that vicinity are obtained in limestone at 90 to 115 feet.

In the Maumee Valley, near Defiance, rock is struck at slight depth, and is exposed in places in that vicinity. The drift on the neighboring portions of the moraine probably has a thickness as great as the difference in altitude between the valley and the moraine, or 60 to 80 feet. North

from the Maumee the thickness is much greater, as appears from the table of wells below.

The following list of deep wells in Fulton County, Ohio, was prepared by Carl D. Greenleaf, of Wauseon, who collected the data from the well owners and well drillers. The wells are principally in the southern half of the county, there being but few made in the northern half. The majority of the wells pass through a large amount of blue till. In some cases a water-bearing gravel is found at the base of the drift, but quite often it is found necessary to sink the wells a few feet into the underlying rock.

Deep wells in Fulton County, Ohio.

Location of well.	Total depth.	Depth in rock.	Head from surface.	Remarks.
	Feet.	*Feet.*	*Feet.*	
Sec. 32, T. 9 S., R. 2 E	120	0	0	Water in gravel near bottom.
Sec. 11, T. 10 S., R. 1 E	120	0	+ 2	A strong flowing well.
Sec. 34, T. 8 N., R. 5 E	113	0	(?)	Water in gravel at top of rock.
Sec. 33, T. 8 N., R. 5 E	178	0	—11	Water in gravel at top of rock.
Sec. 36, T. 8 N., R. 5 E	±120	0	± 5	Several flowing wells about 120 feet deep.
Secs. 1, 2, 3, T. 7 N., R. 5 E	{120 140}	0	± 5	Several flowing wells 120 to 140 feet deep.
George Pound, sec. 3, T. 7 N., R. 5 E.	136	0	+ 3	Throws a strong half-inch stream at 3 feet above surface. Water from gravel.
Sec. 10, T. 7 N., R. 5 E	143	0	(?)	Water in gravel; rock was not reached.
Sec. 13, T. 7 N., R. 5 E	180	12	(?)	Water from gravel above the rock.
Sec. 16, T. 7 N., R. 5 E	135	0	—10	Water in gravel; rock was not reached.
Sec. 23, T. 7 N., R. 5 E	227	70	—25	Salt water obtained in the rock.
Sec. 24, T. 7 N., R. 5 E	226	69	—25	Salt water obtained in the rock.
Sec. 24, T. 7 N., R. 5 E	218	50	—14	Water found in the rock.
Sec. 25, T. 7 N., R. 5 E	150	0	—15	Water in gravel at top of rock.
Sec. 25, T. 7 N., R. 5 E	150	8	—15	Water from gravel above the rock.
Sec. 26, T. 7 N., R. 5 E	130	0	—17	Water in gravel at top of rock.
Sec. 26, T. 7 N., R. 5 E	160	3	—14	Water from the rock.
Archbold village	146	2	(?)	Water from the rock.
J. Sigg, sec. 11, T. 7 N., R. 6 E., 2 miles north of Wauseon, on crest of moraine.	280	80	Dry.	Nineteen wells were bored, of which this is the deepest: all dry.
Sec. 13, T. 7 N., R. 6 E	210	45	—38	Water from the rock.
Sec. 14, T. 7 N., R. 6 E	180	10	—40	Water from the rock.
Sec. 15, T. 7 N., R. 6 E., 2 miles northwest of Wauseon, on crest of moraine.	300	100	Dry.	Two holes were drilled; both dry.

Deep wells in Fulton County, Ohio—Continued.

Location of well.	Total depth.	Depth in rock.	Head from surface.	Remarks.
	Feet.	*Feet.*	*Feet.*	
Sec. 15, T. 7 N., R. 6 E., perhaps ¼ mile south of last boring.	210	10	(?)	Brackish water obtained in the rock.
Sec. 20, T. 7 N., R. 6 E.	210	10	—30	Water from the rock.
Sec. 20, T. 7 N., R. 6 E.	179	16	—15	Water from gravel above the rock.
Wauseon, C. S. Clement	265	115	(?)	Brackish water from the rock.
Wauseon, William Hubbell	154	2	36	The head was at first only 16 feet from top; water suitable for boiler use.
Wauseon waterworks, 1 mile south of city.	159	0	—50	Water from gravel; rock was not reached.
Sec. 24, T. 7 N., R. 6 E.	190	34	—12	Water from the rock.
Sec. 28, T. 7 N., R. 6 E.	228	50	(?)	Water from the rock.
Sec. 28, T. 7 N., R. 6 E.	160	0	—20	Water in gravel at top of rock.
Sec. 30, T. 7 N., R. 6 E.	168	12	—24	Water from the rock.
Near Pettisville, sec. 30, T. 7 N., R. 6 E.	162	0	—22	Water in gravel at top of rock.
Near Pettisville, sec. 30, T. 7 N., R. 6 E.	154	0	—22	Water in gravel at top of rock.
Near Pettisville, sec. 31, T. 7 N., R. 6 E.	164	0	—26	Water in gravel at top of rock.
Sec. 31, T. 7 N., R. 6 E.	150	10	—30	Water from rock; altitude of rock surface about 620 feet.
Sec. 31, T. 7 N., R. 6 E.	226	0	—24	Water from gravel at top of rock; altitude of rock surface about 530 feet.
Sec. 31, T. 7 N., R. 6 E.	218	0	—24	Water from gravel at top of rock.
Sec. 32, T. 7 N., R. 6 E.	225	0	—30	Water from gravel; rock not reached.
Sec. 33, T. 7 N., R. 6 E.	266	50	—30	Water from the rock.
Sec. 33, T. 7 N., R. 6 E.	161	0	—20	Water in gravel at top of rock.
Sec. 33, T. 7 N., R. 6 E.	218	18	(?)	Water from the rock.
Sec. 34, T. 7 N., R. 6 E.	154	0	—22	Water in gravel at top of rock.
Sec. 34, T. 7 N., R. 6 E.	165	0	—30	Water in gravel at top of rock.
Sec. 35, T. 7 N., R. 6 E.	185	0	—30	Water in gravel at top of rock.
Sec. 36, T. 7 N., R. 6 E.	165	10	—30	Water from the rock.
Sec. 8, T. 7 N., R. 7 E.	182	12	—25	Water from the rock.
Sec. 8, T. 7 N., R. 7 E.	160	3	—18	Water in gravel at top of rock.
Sec. 9, T. 7 N., R. 7 E.	156	0	—14	Water in gravel at top of rock.
Delta on Belmore beach	122	12	—22	Water from the rock.
Sec. 14, T. 7 N., R. 7 E., near Belmore beach.	90	1	+ 5	Flows a strong 2-inch stream. Altitude of well mouth about 730 feet.
Sec. 15, T. 7 N., R. 7 E.	176	36	—30	Water from the rock.
Sec. 16, T. 7 N., R. 7 E.	142	7	—22	Water from the rock.

Deep wells in Fulton County, Ohio—Continued.

Location of well.	Total depth.	Depth in rock.	Head from surface.	Remarks.
	Feet.	*Feet.*	*Feet.*	
Sec. 18, T. 7 N., R. 7 E.	160	10	−25	Water from the rock.
Sec. 19, T. 7 N., R. 7 E.	133	(?)	−20	Water from the rock.
Sec. 20, T. 7 N., R. 7 E.	147	12	−16	Water from the rock.
Sec. 21, T. 7 N., R. 7 E.	150	15	−22	Water from the rock.
Sec. 21, T. 7 N., R. 7 E., near Belmore beach.	135	17	−15	Water from the rock.
Sec. 23, T. 7 N., R. 7 E.	97	0	(?)	Rock at bottom.
Sec. 23, T. 7 N., R. 7 E.	137	17	−14	Water from the rock.
Sec. 27, T. 7 N., R. 7 E.	170	0	0	Water flowed when first struck from gravel at top of rock.
Sec. 30, T. 7 N., R. 7 E.	168	(?)	−10	Water from the rock.
Sec. 30, T. 7 N., R. 7 E.	160	20	−18	Water from the rock.
Sec. 31, T. 7 N., R. 7 E.	165	0	−30	Water in gravel at top of rock.
Sec. 31, T. 7 N., R. 7 E.	126	5	(?)	Water from the rock.
Sec. 32, T. 7 N., R. 7 E.	116	23	− 4	Water from the rock.
Sec. 32, T. 7 N., R. 7 E., near Belmore beach.	167	6	− 5	Well overflowed when first made; water from gravel at top of rock.
Sec. 34, T. 7 N., R. 7 E.	80	3	−18	Water from the rock.
Sec. 8, T. 7 N., R. 8 E.	95	2	−12	Water from the rock.
Sec. 9, T. 7 N., R. 8 E.	78	2	−12	Water from the rock.
Sec. 11, T. 7 N., R. 8 E.	85	3	−12	Water from the rock.
Sec. 20, T. 7 N., R. 8 E.	103	12	−16	Water from the rock.
Sec. 22, T. 7 N., R. 8 E.	82	2	−12	Water from the rock.
Sec. 24, T. 7 N., R. 8 E.	87	3	− 6	Water from the rock.
Sec. 29, T. 7 N., R. 8 E.	92	0	(?)	Water in gravel at top of rock.
Sec. 34, T. 7 N., R. 8 E.	72	12	−18	Water from the rock.
Sec. 35, T. 7 N., R. 8 E.	60	2	− 9	Water from the rock.
Sec. 1, T. 6 N., R. 6 E.	140	0	(?)	Water in gravel at top of rock.
Sec. 1, T. 6 N., R. 6 E., near Belmore beach.	142	10	−32	Water from the rock.
Sec. 1, T. 6 N., R. 6 E., near Belmore beach.	64	2	− 8	Water from gravel above the rock.
Sec. 2, T. 6 N., R. 6 E.	175	4	(?)	Water from gravel above the rock.
Sec. 2, T. 6 N., R. 6 E.	142	10	−32	Water from the rock.
Sec. 5, T. 6 N., R. 6 E.	182	0	Dry.	Four holes were bored; all dry.
Sec. 6, T. 6 N., R. 6 E., near crest of moraine.	180	0	−42	Water found in gravel; rock not reached.
Sec. 7, T. 6 N., R. 6 E.	175	40	−22	Water from the rock.
Sec. 7, T. 6 N., R. 6 E.	135	0	−18	Three wells, 132 to 135 feet deep, obtain water at top of rock in gravel, head 17 to 22 feet from surface.

Deep wells in Fulton County, Ohio—Continued.

Location of well.	Total depth.	Depth in rock.	Head from surface.	Remarks.
	Feet.	*Feet.*	*Feet.*	
Sec. 8, T. 6 N., R. 6 E	142	0	−24	Water in gravel at top of rock. Three others, 126 to 137 feet, from same bed of gravel.
Sec. 10, T. 6 N., R. 6 E., near Belmore beach.	122	2	− 7	Water from the rock.
Sec. 12, T. 6 N., R. 6 E	181	41	(?)	Water from the rock.
Sec. 4, T. 6 N., R. 7 E	89	5	− 5	Water from the rock.
Sec. 5, T. 6 N., R. 7 E	100	0	− 8	Water found in gravel.
Sec. 8, T. 6 N., R. 7 E	97	0	(?)	Water in gravel at top of rock.
Sec. 9, T. 6 N., R. 7 E	61	3	−11	Water found in rock; a neighboring well 82 feet.
Sec. 10, T. 6 N., R. 7 E	90	22	−10	Water found in rock.
North part of T. 6 N., R. 8 E	82	12	−14	Several wells in rock at 65 to 82 feet.

A buried channel shown in the above table in a boring near Pettisville in sec. 31, T. 7 N., R. 6 E. appears to lead eastward, passing about 1½ miles south of Wauseon, where it is filled with 225 feet of drift, and thence north of east. Its course was roughly determined by Orton for a distance of about 9 miles by means of well borings, there being no surface indications of its position.[1] Orton in the paper just cited also made the following statement concerning the drift deposits near Wauseon:

> The uppermost 10 to 15 feet consists of yellow clay, oxidized. Below comes blue clay, often so charged with slate fragments and waste as to be almost black. Thin seams of sand are irregularly distributed through the mass. Large bowlders, though rare, are not unknown. The boundary between the yellow and blue clays is not sharp or well defined. The change in color simply marks the line to which the surface water is able to descend. The blue clay reaches a general thickness of 130 to 150 feet. Below it about 5 feet of hardpan is found. This is here described as cemented gravel. Under it a few inches of sand are usually found, and then the Ohio shale is reached.

Many of the Fulton County wells contain a small amount of inflammable gas which is usually struck at the base of the drift. It is probably derived from the underlying shale rather than from decomposition of organic matter in the drift. The salinity of the water obtained in the Ohio shale is

[1] Rock waters of Ohio, by Edward Orton: Nineteenth Ann. Rept. U.S. Geol. Survey. Part IV, 1899, p. 708.

quite general, though seldom so strong as to render the water unfit for use. The drift deposits also yield a slightly saline water, the salt being obtained probably from the shale fragments in the drift.

SILT DEPOSITS BENEATH MORAINIC DEPOSITS.

Along several valleys in northern Ohio there are heavy deposits of silt beneath the till, which are of considerable interest, not only because of their great amount, the depth being in places fully 200 feet, but also because of their position beneath deposits of till and coarse assorted material. E. W. Claypole some years ago called attention to the silts in the Cuyahoga Valley in a paper entitled "The Lake age in Ohio," read before the Edinburg Geological Society,[1] and outlined the probable extent, in this and other valleys tributary to the Lake Erie Basin, of lakes in which it is supposed the silts were deposited. This outline was based largely upon a hypothetical conception as to the position of the ice margin, the lakes being considered glacial foot lakes, held between the retreating ice sheet on the north and the Great Lakes–Ohio divide on the south, with outlets across the divide into the Ohio drainage system. The history of the deposition of these silts proves to be more complex than the paper leaves the reader to suppose, since the occurrence of morainic deposits upon their surface shows clearly that they are of earlier date than these moraines. Furthermore, the actual outline of the ice margin (as shown by its moraines) is so different from Claypole's theoretical outline that his mapping of glacial foot lakes needs revision, there being bulky moraines in the midst of the districts where he supposed lakes to have been, and in which no evidence has yet been recognized of deposition in lake water. The Fort Wayne and Wabash moraines, in their distinct portions in northern and western Ohio, carry little silt on their surfaces and are not underlain by heavy deposits of silt, such as underlie the moraines of this series in the Cuyahoga Valley and other valleys in the hilly district, though they cross the districts where the supposed lakes were located. The geographic distribution of these silts is, therefore, much more restricted than Claypole's maps indicate. On the Cuyahoga Valley and in the Grand River Basin the deposits are rather extensive, being 1 to 3 miles in width and 100 to 200 feet or more in depth, but in Chagrin, Rocky, Black, Vermilion, Huron, and Sandusky River

[1] Trans. Edinburg Geol. Society, 1887.

valleys their amount is very slight, the greater part of the sections exposed in their bluffs being ordinary till with little or no surface capping of silt, and with only occasional exposures of silt beneath the till. The slight exposures which occur may indicate that there were extensive deposits of silt in these valleys previous to the last ice invasion, the greater part of which was removed by the advancing ice sheet. In the Cuyahoga Valley the amount was too great for the ice sheet to remove

The silts exposed along the Cuyahoga are not so fine (at least in the southern portion of the valley) as those in certain other valleys, being sufficiently coarse for the detection of individual grains by the naked eye; they are called quicksand when penetrated in wells. So far as examined by the writer they are entirely free from pebbles, but Claypole reports the occurrence of an occasional pebble and very rarely a large stone. They are horizontally bedded, or nearly so, the thin layers or laminæ being distinctly traceable, since they are in places separated by thin partings of sand. The color is generally blue, though in the upper portion it is yellow to a depth ranging from 10 up to 50 feet or more. The silt is notably siliceous, but contains also considerable lime and iron. The amount of lime increases perceptibly in passing from south to north along the valley, there being in the southern portion scarcely any nodules of lime and but a faint response upon application of hydrochloric acid, while in silts from the northern portion, from the vicinity of Peninsula northward, lime nodules abound. The silt is also more compact in the northern than in the southern portions of the valley. In exposures east of Everett, crystals of sulphate of lime occur in the blue silt. The silt here rises in a solid bank to a height of 225 feet (barometric) above the river or about 360 feet above Lake Erie, and is capped by 15 to 20 feet of till in which large bowlders are embedded. The yellow silt here has a thickness of about 50 feet, the greatest thickness observed in any exposure along the valley. The highest observed altitude of the silt is in the lowland tract west of Akron (which leads from the Cuyahoga through Copley Marsh to the Tuscarawas River), where it reaches an altitude 375 to 400 feet above Lake Erie. It stands higher here than in the valley that leads through Akron along the line of the Ohio Canal. In each valley there are heavy deposits of gravel or other coarse material above the silt. In the western valley there is till as well as sand and gravel; in the eastern, sand and gravel alone are reported. The

summit in the valley west of Akron, as shown by the survey of the Northern Ohio Railroad, stands 425 to 435 feet above Lake Erie, while the summit along the Ohio Canal is 396 feet. In the northern portion of the Cuyahoga Valley the upper limit of the silt decreases to 200 feet or less at the borders of the old lake terraces.

In the other valleys tributary to Lake Erie the silt deposits which have been observed beneath the till have the compact texture and nearly entire freedom from pebbles of those in the northern portion of the Cuyahoga Valley, and, like them, contain a large amount of lime, as shown by nodules and by effervescence with hydrochloric acid. In the valley of Chippewa Creek and River Styx, which lead southward into the Tuscarawas, the silt deposits are known only by records of wells bored in them, and the writer had no opportunity to see specimens from these wells. The streams which lead northward from the continental divide are more rapid than those leading southward, and consequently have deepened their valleys sufficiently to expose nearly the whole section down to the rock floor.

It is not improbable that silt deposits similar to those exposed along these northward-flowing streams occur also beneath considerable portions of the low interfluvial districts of northern Ohio, whose altitude is but little above the streams, as is the case between the tributaries of Black River and between Black and Rocky rivers, but no exposures were observed in that district which reached the bottom of the till. In the hilly districts from Rocky River eastward the silts are apparently confined to the valleys.

The age of these silts and the conditions under which they were deposited afford material for much study and speculation. The silts may represent several distinct depositions at intervals widely separated, though no evidence was found to support this conception, the heavy deposits on the Cuyahoga presenting, so far as examined, no unconformable beds and no alternations of oxidized and unoxidized silts. The silts were probably deposited, as suggested by Claypole, in bodies of water outside the ice sheet, the ice sheet acting as a barrier to prevent northward drainage of the water, though it is possible that in some cases they are the deposits of subglacial waters. The scarcity of coarse material in these deposits, however, seems to strongly oppose the hypothesis of subglacial deposition. The fringing lake may have been formed either during an advance or a retreat, or have embraced both an advance and retreat in cases where the ice failed

to reach to the divide, the size of the lakes varying with the position of the ice margin.

The greater altitude of the silts at the southern end of the Cuyahoga Valley than at the northern presents an interesting problem. The silt may have reached, at one time, as great altitudes along the sides of the northern portion of the valley as it presents on the southern, and have been removed afterward by the advancing ice sheet or concealed by its morainic deposits; or it may never have had as great altitude in the northern as in the southern portion of the district, the northern portion being a deep-water and the southern a shallow-water deposit. Since it is a partially concealed deposit its limitations, both geographic and hypsographic, are difficult to determine.

The extreme rarity of pebbles seems difficult to explain, for if the silt were deposited in narrow lakes outside the ice sheet it is to be expected that tributaries would discharge large amounts of coarse material with the fine into the valleys occupied by these lakes, which would make a perceptible increment to their deposits. This coarse material might, however, have been dropped at the borders and only the fine material have passed out into the midst of the lake. A more careful examination of the gorges tributary to the valleys may throw light upon this matter.

STRIÆ.

The striæ of this district, so far as observed by the writer or reported by previous observers, are represented on the glacial maps (Pls. II, XI, XIII, and XV), and their bearings are given in the table of striæ below. In general, the striæ bear directly toward the moraines; thus, in the vicinity of the lower course of the Cuyahoga, they bear southeastward; in the Sandusky-Scioto Basin, southward; in the Maumee Basin, west of the Sandusky River, southwestward to westward, while in southeastern Michigan the bearing is north of west. There are, however, slight changes of course in the ice currents, shown by cross striation or by lack of harmony in the bearing of striæ in neighboring districts, which may be better comprehended by reference to the maps than by a description.

The greatest variation on any single surface which the writer has noted is that east of Vermilion River, near the line of Erie and Huron counties, where the striæ appear at nearly all angles, from S. 19° W. to S. 77° W., their prevailing bearing being S. 35° W. They all consist of

short lines, none of them exceeding a yard in length, while many are out 6 to 12 inches. A few of them are curved, with their convex side toward the south. The best-defined curved striæ are about 2 feet in length, and their departure from a straight line within that distance is fully 2 inches.

Gilbert reports an observation on West Sister Island, in Lake Erie, showing still greater difference in bearing, there being a general glaciation S. 80° W., and a single observation of striation in a north-south direction which he designates the "intersecting series."[1] He considers the southward striation merely a local feature formed by the retiring glacier at a time subsequent to the heavy glaciation, the striæ being parallel to a steep bluff over which the older grooves rise obliquely.

Still greater divergencies were noted by W H. Sherzer in southeastern Michigan,[2] the range being from about S. 6° W. to N. 20° W., or 154°. In that region a southwestward movement was followed by a northwestward one.

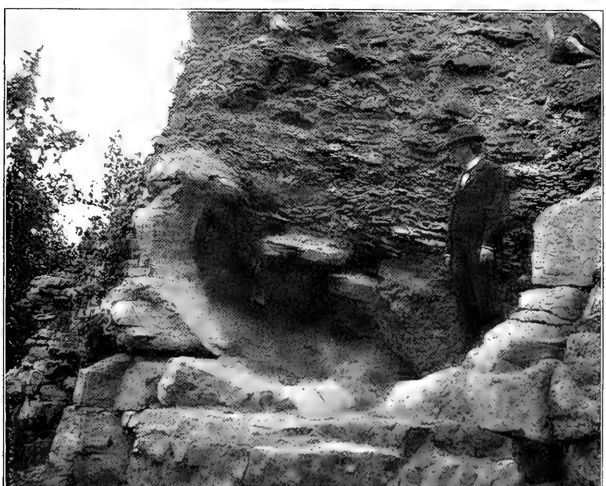
Winchell has reported cross striæ in Seneca Township, Seneca County, Ohio, in which the older set bear S. 5° E. and the later and intersecting series S. 23° W.

Chamberlin has called attention to the disruptive crescentic gouges displayed in the surface of the quarries at West Amherst,[3] whose concave side is turned toward the point of origin of the ice movement. Crescentic cracks of this class he considers the natural result of a movement in which the gouging agent is master of the situation. The "chatter marks" displayed in many striated ledges in other districts resemble these crescentic cracks in frequently having the form of a crescent, but they have their convex side toward the origin of the ice movement. These Chamberlin regards as the result of a movement in which the gouging agent is not the master of the situation, but is dragged across the rock ledges.

The remarkable phases of glacial action on the islands of the western end of Lake Erie and in Marblehead Peninsula have been so well described by Gilbert, Chamberlin, Wright, and others that further remarks concerning them seem unnecessary. Plate XVII furnishes two illustrations of heavy glaciation. The movement across these islands which produced the grooves and striæ was perhaps a late one, when the ice had only the Maumee Basin in which to deploy. There are several striated exposures in northern

[1] Geology of Ohio, Vol. I, pp. 538, 539.
[2] Geol. Survey Michigan, Vol. VII, 1900, pp. 128–132.
[3] Seventh Ann. Rept. U. S. Geol. Survey, pp. 219, 220.

A. GLACIATED SURFACE ON MIDDLE BASS ISLAND, IN LAKE ERIE.



B. LARGE GLACIAL GROOVE ON MARBLEHEAD PENINSULA, NEAR LAKESIDE, OHIO.

Ohio which apparently belong in this late series. For example, at South Euclid and near Berea, and in the Sandusky Valley north of Tiffin, the movement was southwestward, corresponding well with that on the islands of Lake Erie, but somewhat out of harmony with the moraines and with the movements a few miles to the south. It is probable, therefore, that in the closing stages of glaciation, after the Scioto and Miami lobes were absorbed, the ice movement assumed more nearly the direction of the longer axis of the Lake Erie Basin than it had at the time these lobes were in existence.

List of striæ between the Defiance moraine and the west end of Lake Erie.

Location.	Bearing.	Observer.
Newberry Township, Geauga County	S. 50° E	Read.
Chester Township, Geauga County	S. 70° E	Read.
Russell Township, Geauga County	S. 50° to 70° E	Read.
Russell Center, 1 mile southeast of	S. 35° to 55° E	Leverett.
Bainbridge Township, Geauga County	S. 49° E	Whittlesey.
Solon Township, Cuyahoga County	S. 45° E	Whittlesey.
Solon Center, 1 mile north of	S. 20° E	Leverett.
Twinsburg, Summit County	S. 30° to 45° E	Leverett.
Hudson Township, Summit County	S. 35° to 90° E	Read.
Boston Ledges, Summit County	S. 30° to 45° E	Read.
Boston Ledges, Summit County	W. to E	Read.
Peninsula, Summit County	S. 10° to 20° E	Leverett.
Independence, Cuyahoga County	S. 20° E	Whittlesey.
Brighton, 1½ miles south of	S. to S. 10° E	Leverett.
North Linndale, 2 miles southeast of	S. 5° to 10° W	Leverett.
Berea, 2 miles east of	S. 22° to 34° W	Leverett.
County line north of Brunswick	S. to S. 30° E	Leverett.
West Amherst, Lorain County	S. 30° W	Leverett.
Henrietta, Lorain County	S. 20° to 35° W	Leverett.
Birmingham, 2 miles south of	S. 19° to 77° W	Leverett.
Townsend Township, Huron County	S. 45° W	Read.
Sandusky (8 observations)	S. 75° to 81° W	Newberry.
Put-in-Bay Island, Lake Erie	S. 80° W	Newberry.
Put-in-Bay Island, Lake Erie	S. 15° W	Newberry.
South Bass Island, Lake Erie	S. 80° W	Gilbert.
Kelleys Island, Lake Erie	S. 60° to 80° W	Newberry.
West Sister Island, Lake Erie	S. 80° W	Gilbert.
West Sister Island, Lake Erie	N. to S	Gilbert.
Bellevue	S. 65° W	Gilbert.
Republic, 4 miles east of	S. 25° W	Leverett.
Genoa, Ottawa County	S. 65° W	Gilbert.

List of striæ between the Defiance moraine and the west end of Lake Erie—Continued.

Location.	Bearing.	Observer.
Genoa, one-half mile north of	S. 60° W	Winchell.
Section 18, Harris Township, Ottawa County	S. 18° W	Winchell.
Portage River, west line of Sandusky County	S. 53° W	Winchell.
Section 35, Jackson Township, Sandusky County	S. 55° W	Winchell.
Section 7, Portage Township, Wood County	S. 50° W	Winchell.
Section 12, Freedom Township, Wood County	S. 50° W	Winchell.
Section 9, Freedom Township, Wood County	S. 50° W	Winchell.
Otsego, Wood County	S. 65° to 68° W	Winchell.
Sylvania, Lucas County	S. 50° W	Gilbert.
Monclova, Lucas County	S. 62° W	Gilbert.
Fish's quarry, Lucas County	S. 55° W	Gilbert.
Whitehouse, Lucas County	S. 50° W	Gilbert.

OUTER BORDER PHENOMENA.

SMALL GLACIAL LAKES.

The position of the Defiance moraine being in large part on the slope toward Lake Erie, the facilities for discharge of glacial waters during its production are not likely to have been so good as in the preceding moraines. It is probable that small lakes were formed along the south border of the ice which found discharge either southward across low places on the divide or westward along the front of the ice sheet.

One of these small lakes would be the slightly expanded Lake Cuyahoga, which had its discharge southward past Akron, as indicated on page 578. Another lake was apparently held in the south part of the Black River drainage basin and found its discharge along a channel leading southward from Lodi through the Fort Wayne moraine to Killbuck Creek at an altitude a little more than 900 feet above tide.

From the Vermilion River westward there was drainage along the ice margin to Lake Maumee, but the water leading westward from the Vermilion drainage basin was apparently gathered into a narrow lake in the Huron River Basin near New Haven that discharged past Attica to another narrow lake in the Sandusky Basin. The latter discharged westward from near Carey to Lake Maumee at Findlay. The line of discharge past Carey is marked by a definite channel brought to notice by Winchell.[1]

[1] Geology of Ohio, Vol. I, 1873, pp. 626-628; with map of channel.

The chain of lakes and connecting channels just outlined show a decrease in altitude in passing from east to west. The channel in the Vermilion drainage basin is estimated to have an altitude about 950 feet above tide and descends about 25 feet to reach New Haven in the Huron River Basin. The extensive New Haven Marsh, which extends westward from the Huron Basin near New Haven to the head of Honey Creek (an eastern tributary of the Sandusky), near Attica, stands about 925 feet above tide, and probably represents nearly the level of the lake in the Huron Basin. There was a descent of about 100 feet along Honey Creek from this lake to the one in the Sandusky Basin, for the outlet of the latter near Carey is only 815 to 820 feet above tide. The descent along this outlet from Sandusky Lake to Lake Maumee at Findlay was about 40 feet in a distance of 15 miles.

The head of the outlet of Sandusky Lake is reported by Winchell to carry a deposit of black muck ranging in depth from 4 or 5 feet up to 8 feet or more, which is underlain by a marly or calcareous blue clay. These deposits have probably accumulated since the channel was abandoned

RELATION OF THE DEFIANCE MORAINE TO LAKE MAUMEE.

Several references have already been made to the beaches and outlet of the glacial Lake Maumee, but its relation to the Defiance moraine has not been clearly stated. As the beaches and outlet are discussed in some detail farther on, only the general relations to the Defiance moraine will now be considered.

When the Defiance moraine was traced by Gilbert, some thirty years ago, it had not been determined whether the lake which discharged through the Fort Wayne outlet into the Wabash was held at its high level by the ice sheet or by a land barrier. Gilbert seems at that time to have favored the land-barrier hypothesis and considered the lake entirely postglacial, while Newberry considered the ice dam formed by the retreating ice sheet an adequate cause, and referred it to the closing part of the Glacial epoch.[1] It soon became evident that the land-barrier hypothesis had no foundation in the topography of the region, and attention was directed to the question of the relation of the beaches to the moraines of the great ice sheet. Gilbert took the lead in this investigation and discovered that the beaches do not

[1] Geology of Ohio, Vol. I, pp. 549–552; Vol. II, pp. 8, 51, 52.

completely encircle the basin, but terminate in a successive series from higher to lower in passing from northern Ohio eastward into southwestern New York. He did not, however, attempt to map the moraines which were formed subsequent to the Defiance moraine and work out the full correlation. A part of this work has fallen to the present writer, and it is now possible to speak with some assurance concerning the correlations on the south shore of Lake Erie. The correlations on the north are not fully worked out, though studies by Taylor have thrown much light upon them.

In an early stage of the investigation the writer supposed that the Defiance moraine was nearly the full correlative of the upper beach of Lake Maumee, and that with the retreat of the ice sheet from that moraine the lake level soon fell a few feet to the Leipsic or second Maumee beach. This interpretation, which was published in 1892,[1] was erroneous in that it limited the upper beach to the district outside of the Defiance moraine. It is now known to be developed as far east as Cleveland, and to be identical, from Leipsic eastward to Cleveland, with the beach which in 1892 was supposed to be the second Maumee or Leipsic beach; it has not been found east of Cleveland. It has also been traced northward in Michigan to the Imlay outlet, near Imlay City, and may be traced still farther north. The course and known extent of the beach may be seen in Pl. II.

These later developments, while indicating that the lake held its highest level long after the Defiance moraine had been formed, do not in the least antagonize the hypothesis that the ice sheet constituted the limiting barrier on the northeast border of the lake. The fading out of the beach near Cleveland and the connection there with a moraine later than the Defiance brings the strongest possible support to that hypothesis, as will be shown farther on. The lowering of the lake level obviously depends upon a change in the lake outlet, and, as in this case, it may have no relation to the withdrawal of the ice sheet from a given moraine.

It having been ascertained that the Defiance moraine is not the full equivalent of the upper beach of Lake Maumee, the question to be determined is what fraction of the upper lake stage the moraine equals. As Lake Maumee occupied the district outside of the Defiance moraine while the moraine was forming, it may be thought that a comparison of the strength of that part of the beach with the part formed inside the moraine

[1] Am. Jour. Sci., 3d series, Vol. XLIII, pp. 284–290.

will furnish a ready answer to this question. The solution is, however, not so easy as might be expected, for the beach varies greatly in strength in both districts. It is weak where the descent on the lakeward side is very gradual, and comparatively strong where the descent is rapid. It so happens that in much of the shore outside of the Defiance moraine the lake plain has exceptionally slight descent, often but 5 to 10 feet per mile, while in the part of the shore inside the moraine it is, on the whole, rather rapid.

In so far as favorable conditions in one district exceed those in the other a false impression of relative strength is likely to be gained. The impression which the writer has obtained by comparing the portion of the south shore of Lake Maumee outside the Defiance moraine with that inside is that the latter is fully as strong as the former. But upon comparing the northwest shore outside the moraine with that inside there was found to be a decidedly stronger beach outside the moraine and that, too, where slopes appear to be similar. The portion outside seems to have at least double the strength of that inside. The study has not, however, been sufficiently thorough to justify a more precise statement of the relative length of the part of the upper lake stage involved in the deposition of the Defiance moraine. It can only be stated that on the northwest shore it is sufficient to cause a marked contrast between the part of the beach outside and that inside of the moraine. Possibly the part outside required twice the time of that inside, but this seems a rather high estimate. The estimates of relative lengths should be supported by more data than have thus far been collected.

INNER BORDER PHENOMENA.

The district covered by this description includes, on the east side of the Cuyahoga, only a narrow strip lying between the Defiance and the Cleveland moraine, and on the west side of that river a strip lying between the Defiance moraine and the upper beach of the glacial Lake Maumee. The width of this strip is variable, being 4 to 8 miles from the meridian of Findlay eastward to the Sandusky River, 12 miles on the meridian of Bellevue, a very narrow strip near the meridian of Norwalk, and 15 to 20 miles from the meridian of New London eastward to Berea, beyond which it decreases to a breadth of about 10 miles at the Cuyahoga River and 2 to 3 miles at Chagrin River, east of which it remains narrow.

TOPOGRAPHY.

From Findlay eastward to the west fork of Rocky River this is a nearly plane tract with a decided northward slant, the only prominent exceptions being a small area in northwestern Lorain and eastern Erie counties, covering two to three townships, where occasional sandstone hills rise above the general level. From Rocky River eastward it embraces a hilly district with only a narrow fringe of plane country next to the beach line along its north border.

In the district lying west of Rocky River there is some variety in the surface contours, although no part is decidedly morainic. The district between Rocky and Black rivers is exceedingly flat, and so is the narrow tract east of Rocky River between the beach line and the hilly districts, there being scarcely any knolls so much as 5 feet in height. From Black River westward there are many low swells 3 to 5 feet, and a few 10 feet, in height. They are somewhat irregularly distributed, some sections being thickly dotted with them, while others carry scarcely any. The most conspicuous drift features noted in this district are an esker in Hartland Township, Huron County (described below), and a knoll in the southwest part of the same township, which rises abruptly about 30 feet above the bordering country. There is also a small district south of the Lake Shore and Michigan Southern Railway, in eastern Huron County, where the surface is somewhat uneven, there being valley-like depressions surrounding island-like knolls whose height is but little above that of the bordering plain. The valleys widen and contract after the fashion of those included among the knolls of the moraine. In the hilly districts the drift is seldom aggregated in knolls, there being only an occasional knoll so much as 10 feet in height.

THICKNESS OF THE DRIFT.

The thickness of the drift, aside from buried valleys, probably averages no more than 30 feet and may possibly average but 20 feet. In the buried valleys its thickness is much greater, as the rock floor of the larger valleys was probably cut down below the level of Lake Erie, if we may judge from data at Cleveland cited above (p. 595). Remarkably few borings were found which penetrate deeply into the old valleys. Attention has already been called to a line leading from New London northeastward through

Wellington, where numerous wells have penetrated 75 to 110 feet of drift. Aside from this there were but few places found where the drift exceeds 50 feet. One is at W. H. Todd's, 2 miles north of Florence, in Erie County, where rock is struck at a depth of 77 feet. A mile south of this well is a sandstone hill which rises to a height of 40 to 50 feet above the well mouth. Another is in Hartland Township, Huron County, at a schoolhouse and at the base of the Hartland esker. This well has a depth of 75 feet and does not reach the rock. Around the northern end of the esker the drift has a thickness of only 10 to 20 feet. A gas well in Rocky River valley, at Columbia Center, Lorain County, passed through 40 feet of drift. The well mouth is 20 to 25 feet below the level of the bordering till plain. At Brunswick Center, Medina County, G. B. Babcock has a well 50 feet deep which did not reach rock, but rock comes to the surface just north of the village at a higher level than the well mouth.

STRUCTURE OF THE DRIFT.

The drift is mainly till, though the valleys, as already indicated, contain considerable silt beneath the till, and there are thin sheets of sand and gravel on the uplands interbedded with the till. It is from these sheets of sand and gravel that the wells are usually obtained, the abundance or scarcity of good water depending upon their thickness and extent. The till ordinarily contains a large amount of clay, but in the midst of the sandstone hills of northwestern Lorain and eastern Erie counties it is of a sandy nature, furnishing a good illustration of the effect of the local rocks upon the structure.

BOWLDERS.

The number of bowlders on this inner border tract is not great, though in certain limited districts they abound. One such district is crossed on the road from Strongsville to Columbia Center. Another is in eastern Seneca County, along the east-west center road in Thompson Township west of the center. Perhaps other similar places occur within the limits of this district, but they have not been noted.

THE HARTLAND ESKER.

Aside from the beds of assorted material which are interbedded with the till, there are occasional surface deposits of gravel or sand in the form of knolls and ridges, and also in plane tracts.

The only conspicuous gravel ridge observed is the Hartland esker. This ridge lies on a very level till plain in the northeast part of Hartland Township, Huron County, its southern end being near the east-to-west center road, and 1½ miles east of Hartland Center, and its length about 2 miles. The trend is nearly due north to south, but the ridge winds slightly, varying 20° or more from a due north-south line. The general height is 10 to 12 feet, but in places a height of 20 feet is attained. The width, including slopes, is only 75 to 125 yards. It is a continuous ridge, except for a gap near the middle a few yards in width. Two basins were observed on the crest of the ridge, one of which is fully 10 feet in depth and contains a small pond. The northern half of the ridge is sharper and higher and contains coarser material than the southern half.

The largest exposure noted in the esker is at a gravel pit in the northern half near the schoolhouse referred to above. It is opened at a place where the ridge makes a sharp curve from a south-southeast course to one west of south. It has been worked back from the outer side of the curve to the inner, the best exposures being at points which show the structure of the inner curve. There is a confused mass of cobble, gravel, and sand, with slight clay admixture, and only indistinct lines of bedding. These, so far as made out, are nearly horizontal. On the outer curve of the ridge the bedding appears to be more distinct than on the inner. Several slight exposures occur between this large pit and the southern end of the ridge. They usually show a thin bed of sandy clay at the surface, which is sparingly interspersed with pebbles, beneath which is gravel of medium coarseness. Residents state that the wells along this portion of the ridge frequently strike a bed of sand which yields some water, after which they enter till near the level of the bordering plain.

There is no fan or gravel plain at the south end of this esker, but on the contrary, it terminates abruptly in the till plain. About 2 miles south, however, is found the northern end of the spur of the Defiance moraine described above, which lies along the east side of Vermilion River, and since this spur is composed mainly of gravelly knolls and is so nearly in line with the esker, it is thought that it may have been formed by the same glacial stream which formed the esker, the interval of 2 miles between the esker and the spur having been unfavorable for the production either of an esker or of gravelly knolls. Just how the glacial waters deposited such

ridges and knolls and why the gaps exist are interesting questions which afford room for speculative inquiry but which are not well enough understood at present to warrant the rendering of an opinion.

THE OLD VALLEY OF ROCKY RIVER.

The changes of drainage in this region, especially in the plane portion of it, have been such that several of the streams are in channels entirely postglacial, draining territory whose preglacial drainage lines are completely filled with drift. In one conspicuous instance, however, the preglacial course has been abandoned, but not concealed, viz., that of the East Fork of Rocky River. The fact was announced by Newberry[1] that the present mouth of Rocky River does not coincide with its ancient mouth, but comes to the lake shore 2 miles east of it. The river, however, touches its old channel 2 miles above its mouth, one bluff being composed of rock while the other is composed of till. A few years after Newberry's reports were published, Dr. D. T. Gould, of Berea, Ohio, discovered that the old course of the East Fork of Rocky River may be traced from the point where Newberry left it (2 miles above the mouth of Rocky River), southward into Strongsville Township, Cuyahoga County, where it becomes coincident with the present course and continues so to the head of the stream. The present course of the stream is nearly parallel with the ancient one throughout this distance (about 15 miles), lying 1 to 1½ miles west of it. The old course is indicated superficially by a shallow, troughlike depression, about one-half mile wide and 10 to 40 feet deep, and its existence is confirmed by borings which show that no rock lies near the surface of this depression. The deepest boring (one near the Big Four Railroad) is reported by Gould to have penetrated about 200 feet of drift before reaching rock, showing the rock floor to be nearly as low as the surface of Lake Erie.

Along the ancient course, from the vicinity of Berea southward for nearly 15 miles, the Berea grit is wanting for a space of 1 to 1½ miles or more, while along the present stream throughout that distance the bed and bluffs are composed of this formation. The present valley is a narrow gorge but a few rods in width, while the ancient one has a width of a mile or more.

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[1] See Geology of Ohio, Vol. I, 1873, pp. 171–172; Vol. II, 1875, p. 16.

Gould has published the results of his studies in a Berea newspaper,[1] showing in some detail the nature of the evidence bearing upon the question of change of drainage and the manner in which the evidence was brought to his notice. Some of the interesting features along the line of the ancient valley he describes as follows:

Extending along the whole eastern border of this village [Berea], and distant from it about a mile, is a chain of what were at one time swamps and small, shallow ponds. These have within a few years been drained, cleared, and brought under cultivation, and to-day are the somewhat famous onion fields of Berea. There are seven of these swamps, each distinct from the other, the divisions in each case being ridges of clay loam of different heights, some being not more than 10 feet and others 20, 30, and in one case nearly 40 feet. The general direction of this chain of swamps is nearly north and south; the direction of the dividing ridges is northeast to southwest. The soil along the crest of these ridges is very noticeably sandy, while the general country everywhere east and west of them has a stiff clay soil. With the exception of one swamp the drainage is from one to the other through gaps in these ridges, which have been broken through by the contained water in each, into a general reservoir near the center of a swamp much larger than all the others combined. This reservoir or pond is Lake Abram, and the reclaimed marsh around this pond and also the detached marshes constitute the Berea onion district. This chain of marshes is 2½ miles in length.

The cross ridges mentioned by Gould, which separate the basins, are composed in the main of ordinary till, though there are places where gravel may be obtained from them. They are evidently glacial deposits, and the basins also date from the glacial period. One basin was observed about one-half mile south of Lake Abram, which is situated on the slope nearly up to the top of the bluff-like border of the trough. At the southern end of the chain of swamps this old channel is completely filled, so that its altitude is fully as high as the bordering plain and slightly above the level of the bluffs of the present stream. The stream, no doubt has taken its present course because of lower altitude, or at least of less obstruction to its course there than along its old route. It is not improbable that the peculiar features which this old valley displays were present in other deeply filled valleys of the drift-covered region, especially those in hilly districts, and may represent the form of channel in which many of the postglacial streams began their work. It is certain that many of the channels occupied by postglacial streams, when following their preglacial courses,

[1] The Berea Advertiser, April 16 and 30, 1886.

vary remarkably in width. The amount of postglacial erosion may therefore be much less than the size would indicate, a portion of the channel having never been filled.

SECTION IV. MORAINES OF THE ERIE LOBE.

CLEVELAND MORAINE.

The Cleveland moraine is the next one later than the Defiance. As a land-laid moraine it appears to be developed no farther west in Ohio than the southwestern part of the city of Cleveland, but its continuation as a water-laid moraine may be traced at points west from Cleveland. Possibly it will be found near a line recently suggested by Taylor, a short distance back from the shore of Lake Erie from Cleveland to Toledo, and thence northward into Michigan; it would then perhaps be more appropriately termed the Toledo moraine, a name suggested by Taylor.[1] Neither Taylor nor the writer has, however, found conclusive evidence of a moraine along the portion of the line between Cleveland and Toledo, nor for some distance north from Toledo. This being the case, it seems preferable to withhold the name Toledo and apply the name Cleveland, the latter being a prominent city at the southwestern end of the well-defined land-laid portion. This land-laid portion has occasionally been called the Newburg moraine, from the part of Cleveland in which it is found, but it seems preferable to substitute the name of the well-known city rather than to adopt the name of one of its suburbs.

DISTRIBUTION.

The westernmost point at which this moraine has been recognized is on the west bluff of Big Creek, opposite North Linndale, near the southwestern limits of the city of Cleveland. To the south, west, and north of this place there is a very level surface, on which no morainic features were detected. From North Linndale the course of the moraine is nearly due east along the south side of Big Creek to its junction with the Cuyahoga in the southeast part of Cleveland. Upon crossing the Cuyahoga into the part of the city known as Newburg, the moraine, as indicated in Pl. XIII, continues eastward through Randall to the valley of Chagrin River below Chagrin Falls. From this valley the moraine swings abruptly

[1] Bull. Geol. Soc. America, Vol. VIII, 1897, pp. 34, 39; Jour. Geol., Vol. V, 1897, p. 454; Am. Geologist, Vol. XXIV, 1899, p. 15.

northward, passing through Chester Crossroads to the East Chagrin River in the southwest part of Chardon Township. It there swings eastward and passes just north of the village of Chardon to Hampden Center, and thence to the headwaters of the Cuyahoga River in northeastern Geauga County, Ohio.

The moraine then makes a detour to the south in crossing the Grand River Basin. For about 10 miles from the head of the Cuyahoga the course is southward along the divide between the Cuyahoga and Grand rivers. It then swings to the southeast and constitutes a portion of the divide between the Grand and Mahoning rivers, passing through Southington and Champion townships, Trumbull County, and coming to Mosquito Creek 2 or 3 miles south of Cortland. It there turns abruptly northward and crosses over the divide between Mosquito and Pymatuning creeks. It first touches the Pymatuning Valley near the line of Trumbull and Ashtabula counties, and follows the western slope of that valley to the Ohio-Erie divide, about 4 miles northwest of Andover, Ohio. The small glacial tongue encircled by this loop extended but little outside the drainage basin of Grand River. It has a width of about 15 miles at the south end, and perhaps 25 miles at the north, where it became confluent with the main body of the ice sheet.

From the Grand River Basin eastward there is a much more complex morainic belt than to the west, and possibly more time was occupied in its formation than in that of the Cleveland moraine. Between Pymatuning Creek and the Ohio-Pennsylvania line there are three somewhat distinct ridges or members, each from 1 to 2 miles wide. The southernmost passes in an eastward course through West Williamsfield and Williamsfield Center, and after crossing the State line enters the Shenango Valley near the north edge of Jamestown, Pa. The middle member leaves Pymatuning Creek 3 or 4 miles farther north than the southern one, and, bearing south of east across southwestern Andover and northeastern Williamsfield townships, becomes merged with the southern member just east of the State line. The northern member passes from the head of Pymatuning Creek north of east across Leon Township, entering Pennsylvania near Pennline, at the northwest end of Pymatuning Swamp.

No well-defined continuation of the southern and middle members was found on the uplands east of the Shenango, between that stream and

Crooked Creek, and nowhere east from it are more than two members developed.

Drift knolls abound opposite Hartstown, on the east side of Crooked Creek, near the head of the stream. They apparently correspond in age to those in the Shenango Valley at Jamestown. There is a nearly continuous line of knolls from Hartstown northwest to Pennline, along the east side of Pymatuning Swamp, at a right angle to the general trend of the moraine and in about the same direction that the ice moved. It is probably a connecting link between the southern and northern members of the morainic system. At the time the earliest member of this series was forming the ice sheet apparently stood at Hartstown, on the valley of Crooked Creek; at Jamestown, on the Shenango, and near the line of Ashtabula and Trumbull counties, Ohio, on the Pymatuning. These points mark the southern border of the features in these valleys. At the time the latest member was forming the ice sheet apparently stood at the head of Pymatuning Creek, in eastern Ohio, and at the northwest end of Pymatuning Swamp, in western Pennsylvania, and the knolls along this swamp appear to have been formed in connection with the retreat of the ice sheet from Hartstown to Pennline, i. e., from the southeast to the northwest end of the swamp.

The upland between the Pymatuning Swamp and the valley in which Conneaut Creek and Conneaut Lake are situated has scarcely any drift knolls worthy of note, but along the Conneaut Valley there is a line of drift knolls about as long as that on the Pymatuning Swamp, 10 to 12 miles. The southern end is east of Conneaut Lake, and the northern end near Conneautville, Pa. The formation of this line apparently occupied an interval of time similar to that between the formation of the southern and northern members of the moraine in the valleys west from here, the southern end having been deposited when the ice stood at Hartstown and Jamestown, Pa., and the northern when it stood at Pennline, Pa.

On the uplands between the Conneaut Valley and the Cussewago, two feeble moraines were observed, one passing from the southern end of Conneaut Lake north of east into the Cussewago Valley, at the bend 3 or 4 miles west of Meadville, the other passing from near Conneautville to the Cussewago Valley at Crossingville. The Cussewago Valley has drift knolls along its eastern side throughout the interval between Crossingville and the bend of the creek, while the western slope is nearly free from drift knolls.

Between Cussewago and French Creek valleys drift knolls occur, both isolated and in groups, but not forming well-defined belts. In French Creek Valley drift knolls set in near Saegerstown and occupy it as far as the bend west of Cambridge, a distance of 7 or 8 miles. These probably represent only the outer member, for French Creek has here a northeast-to-southwest course corresponding with the general direction of the ice margin. The inner member is apparently represented on Conneautee Creek, a few miles north of Cambridge, near McLane, and on Le Boeuf Creek at Waterford, there being strongly morainic topography in the valleys at these villages, and a well-defined moraine-headed terrace at Waterford. The two members of this morainic belt are more distinctly outlined east from here than they are to the west, and are accordingly traced separately.

The outer member follows the southeast side of French Creek from Cambridge to Le Boeuf and then passes up East French Creek and rises to the uplands. It passes 2 or 3 miles north of Beaver Dam, and enters New York at the extreme southwest corner of the State. In New York it has a northeastward course for several miles, crossing the Western New York and Pennsylvania Railway north of Panama station, and rising onto the uplands between the head of French Creek and Lake Chautauqua, where it attains an altitude about 1,800 feet above tide. The moraine is not well developed on the slope toward Lake Chautauqua, but seems to find its continuation in a sharp cluster of knolls at Jamestown, N. Y., at the southeast end of the lake.

The inner member passes from Waterford, Pa., northeast into New York, crossing the valley of Lake Pleasant at and above the lake, and the north branch of French Creek north of Lowville, Pa., and in western New York it again crosses this creek near its head at Findley Lake. From the north end of Findley Lake its course is slightly north of east past Sherman, N. Y., to the narrows of Lake Chautauqua.

There are occasional developments of morainic topography between these two belts, so that in some of the valleys of Erie County, Pa., and Chautauqua County, N. Y., they are nearly connected, but on the uplands they are distinctly separate moraines.

Some uncertainty is felt concerning the position of the ice margin for a distance 30 miles east from Lake Chautauqua at the time the Cleveland morainic belt was forming. It is a much more broken region than that

west of Lake Chautauqua, there being a difference of more than 700 feet in the altitude of ridges and valleys. The altitude of the high points on a dividing ridge between Cassadaga and Conewango creeks, in northwestern Gerry, eastern Charlotte, and western Cherry Creek townships, in Chautauqua County, is 2,040 to 2,100 feet, as shown by the Cherry Creek topographic sheet, while the broad valleys of Cassadaga Creek on the west and of Conewango Creek on the east of this elevated strip are below the 1,300-foot contour. As both of these valleys are open to the north, the ice sheet was free to extend into them from the Lake Erie Basin. There is a strong probability that it extended down Cassadaga Valley to the mouth of the creek and down Conewango Valley to the vicinity of Kennedy; but it probably fell short several miles of reaching as far south on the intervening uplands and also on the high uplands between Cassadaga Valley and Lake Chautauqua.

The entire valley of Cassadaga Creek and the part of Conewango Creek above Kennedy have broad bottoms standing only a few feet above the creek beds, portions of which are still subject to overflow. Along the borders of each of these valleys, and also on the borders of the valley in which Lake Chautauqua lies, there are accumulations of gravelly, partially assorted drift which rise 40 to 75 feet above the broad bottoms. They are slightly undulatory and in places carry shallow basins. The topography, structure, and position of these deposits seem best explained on the hypothesis that the valleys were filled by tongues of ice at the time they were accumulating. The hypothesis that these benches are remnants of a filling which once extended entirely across the valleys was considered and found to be untenable, for such an erosion as it would call for is greatly out of proportion to the erosion farther down these drainage lines. The hypothesis that the benches represent the borders of a lake was also considered and found to be unsatisfactory. The deposits are evidently to a large extent glacial. The water action which they display seems to be such as might occur in connection with drainage along the border of ice tongues, and not such as would occur on the shore of a narrow lake. The basins and the low swells on these benches give them a striking resemblance to the head of glacial terraces. An examination of the part of the Conewango below Kennedy shows the valley to be occupied by a pitted gravel plain which stands at about the same height as these benches. This pitted gravel

plain leads past the southern end of Cassadaga Valley and connects with a valley that leads down the Lake Chautauqua outlet from the moraine at Jamestown.

Concerning the position of the ice margin on the intervening uplands, but little has been ascertained. On the divide between Lake Chautauqua and Cassadaga Creek the drift surface is generally free from knolls. East of Cassadaga Creek there are notable drift accumulations in Mill Creek Valley, from its mouth near Sinclairville up nearly to its source, a distance of 5 or 6 miles. This constitutes apparently a natural line of continuation for the inner member, which was traced to the narrows of Lake Chautauqua. There seems to be no moraine on the high divide to the east of Mill Creek, but east of the divide along Farrington Hollow for about 3 miles northwest from Cherry Creek village, there are conspicuous drift knolls. The lower course of West Conewango Creek, near Hamlet, is also choked by drift knolls. Those in Farrington Hollow may constitute the line of continuation of the inner member. On the east side of the main Conewango Valley, drift knolls are conspicuous on the lower course of Dry Brook, near Rutledge. They are also numerous north of Leon, where they have filled an old valley which may have been the former line of discharge for Mad Creek. But aside from these two places there are few knolls along this side of the Conewango Valley. At the head of the Conewango Valley there is a well-defined moraine, but it belongs to a later morainic system than that under discussion.

Between Conewango Creek and the South Fork of Cattaraugus Creek there is a high upland, with an altitude 1,900 to 2,000 feet or more, and on this upland drift knolls are comparatively rare. But a well-defined moraine sets in near Maples post-office, about 6 miles east of Cattaraugus village, which seems likely to be the continuation of the Cleveland morainic belt, for it lies a short distance outside the morainic system which farther west is known to be the next one younger than the Cleveland belt. Its general course is indicated on the glacial map, Pl. II, but a more definite outline will be here presented.

From Maples northeastward to the meridian of Machias, a distance of nearly 20 miles, this moraine lies near to and in places constitutes the divide between southern tributaries of Cattaraugus Creek and the headwaters of Great Valley and Ischua creeks, which discharge to the Allegheny River.

It passes about 3 miles south of the village of Ashford Hollow, 1 to 2 miles south of the village of West Valley, and 2 to 3 miles north of Machias.

From near the head of Ischua Creek, about 4 miles southwest of Machias, another moraine leads eastward, passing just south of Machias, and continuing about 3 miles beyond that village. It there becomes obscure, but seems to be continued in a belt that sets in 4 or 5 miles farther east, near Fairview, and leads southeastward past Rushford to the Genesee Valley at Caneadea. Whether this moraine is a member of the same system as that to which the Cleveland belongs is not determined. It may be a correlative of an earlier moraine, but its close association with the supposed Cleveland moraine in the few miles in which it is well developed seems to justify its consideration in connection with that moraine. From Machias eastward to the Genesee the two moraines are separated by a space of but 4 to 8 miles.

Returning to the meridian of Machias, we find that the northern or supposed Cleveland moraine takes an eastward course to Clear Creek (a southern tributary of Cattaraugus Creek) at Sandusky. It there swings northeastward and rises to the elevated divide between the head of Cattaraugus Creek and Wiscoy Creek, a western tributary of Genesee River. On this divide it turns southeastward, but extends a spur northward along the divide to the next morainic system. The village of Eagle stands near the outer border of the moraine at the place where it turns to the southeast.

The moraine is strong for about 3 miles east of Eagle. It is then poorly defined for a couple of miles. It becomes strong again in Cold Creek Valley, in northeastern Centerville Township, and leads down the south side of that valley to the Genesee, coming to that river between the villages of Houghton and Fillmore.

RANGE IN ALTITUDE.

The course of the Cleveland morainic belt being across a hilly region, there are frequent fluctuations in altitude. In many cases the moraine makes a rise of 200 to 300 feet within a space of 1 to 2 miles, and occasionally an even greater rise in an equally short distance. The following table presents the principal fluctuations.

Table showing range in altitude of the Cleveland moraine.

	Feet above tide.
Western terminus, near North Linndale	800–825
Near Randall, Ohio	1,000–1,050
Chagrin Valley	900–950
Near Chardon	1,100–1,200
Highlands west of Grand River	1,200–1,325
Grand River Valley	915–940
Divide between Mosquito and Pymatuning creeks	1,100–1,150
Pymatuning Valley	940–1,000
Ridge between Pymatuning and Shenango	1,075–1,191
Andover geodetic station	1,191
Shenango Valley from Jamestown to State Line	972–1,020
Pymatuning Swamp	1,020–1,050
Divide between Pymatuning Swamp and Conneaut Valley	1,100–1,225
Conneaut Lake	1,082
Divide north of lake	1,100
Dicksonburg	995
Conneautville	920
Highlands between Conneaut and Cussewago valleys	1,175–1,450
Cussewago Valley	1,075–1,150
Creek bed opposite Hayfield (White)	1,095
Highlands between Cussewago and French creeks	1,300–1,500
Moraine at Conneautee Valley	1,275
Ridge between Conneautee and Le Boeuf valleys	1,400
Moraine at Le Boeuf Valley (Waterford station)	1,193
Highlands near southwest corner of New York	1,700
Valley near Panama station	1,550
Highlands west of Lake Chautauqua	1,800
Lake Chautauqua	1,300
Highlands east of Lake Chautauqua	1,800
Cassadaga Valley	1,300
Divide east of Cassadaga Valley	2,100
Conewango Valley	1,300
Divide between Conewango and South Cattaraugus valleys	2,000
Uplands west of Machias	1,900
Valley north of Machias	1,650
Divide near Eagle	2,000
Genesee Valley near Houghton	1,360

The uplands in eastern Chautauqua County, N. Y., as already noted, rise in a few places to an altitude of 2,100 feet, but are generally 1,600 to 1,800 feet. Probably the ice sheet extended to the highest points at the time it was forming the Cleveland morainic belt, for the uplands are 10 to 15 miles farther north than the southern end of Lake Chautauqua and the supposed limits of the ice tongues in Cassadaga and Conewango valleys; but, as above noted, there seems to be no definite moraine on these uplands. The altitude in Cassadaga and the Conewango valleys, as indicated above, is scarcely 1,300 feet. East of Conewango it rises within a few miles to nearly 2,000 feet. From there eastward to the reentrant angle on the divide

west of the Genesee drainage basin it is 1,600 to 2,000 feet, being about 1,600 feet in the valleys and 1,800 to 2,000 feet on the uplands. On the border of the Genesee the uplands are about 1,600 feet, but drift knolls extend down to a terrace about 200 feet above the river level, or 1,360 feet above tide.

RELIEF.

On the uplands west of the Grand River Basin in Ohio, and also within this basin, the relief of the Cleveland moraine ranges from about 15 feet up to 50 feet or more. In the valleys of northwestern Pennsylvania it in places reaches 100 feet, though it is usually much less. On the uplands bordering these valleys the relief seldom exceeds 30 feet. In southwestern New York the relief in the valleys is 20 to 50 feet or more, but on the uplands it is only 15 to 30 feet.

TOPOGRAPHY.

Aside from occasional sharp knolls which appear at intervals throughout the entire length of the moraine, there is usually a swell-and-sag topography, somewhat similar to that displayed by the Defiance and other moraines outside the Cleveland morainic belt. In the portion between Cleveland and the Grand River Basin the knolls are usually but 10 to 15 feet in height, though a cluster of sharp knolls 35 or 40 feet in height was noted on the border of East Chagrin River, 4 to 6 miles west of Chardon.

On the uplands west of Chagrin Falls a short esker ridge appears in the moraine. It is 15 to 25 feet high, 10 to 15 rods wide, including slopes, and is practically continuous for about a half mile. Its trend is N. 50° W. to S. 50° E., or about in harmony with the striæ in that locality. Associated with it and following its southwest side are occasional drift knolls which are elongated in line with the trend of the esker. The easternmost one has a length of about 1,000 feet and width of about 300 feet. Its trend is, however, different from that of the esker, being N. 15° W. to S. 15° E. As this knoll lies southeast of the esker proper, it may mark the line of continuation of the stream which formed the esker.

On the high uplands west of the Grand River Valley the moraine consists of a nearly continuous undulatory ridge on which there are basins as well as swells. The highest points on the ridge stand 35 to 50 feet above the outer border tract, though the general elevation is less than 30

feet. The swells are 10 to 20 feet or more in height, closely aggregated in places, and everywhere so associated as to give a decidedly morainic aspect to the belt. An especially prominent cluster of knolls appears on the line of Hampden and Montville townships, about a mile from their southern boundary, where, over an area of about one-fourth of a square mile, the knolls are closely aggregated and rise sharply to heights of 10 to 40 feet.

Upon entering Trumbull County the moraine descends into Grand River Valley and is well defined on the slopes, though its knolls are low, seldom exceeding 15 feet in height. In the Grand River Valley, in Southington and Champion townships, its surface is uneven, with changes of level as great as 25 or 30 feet within a half mile, but there are few if any sharp knolls. This unevenness is due to irregularity of drift deposition rather than to postglacial erosion, and the well sections show it to be entirely independent of the rock floor under the valley. The moraine presents here a nearly continuous ridge, which rises gradually on the inner border, but rather abruptly on the outer. Two notable gaps occur in it, each about a half mile in width. One, near the southeastern corner of Champion Township, affords an easy passage for the Pittsburg, Youngstown and Ashtabula Railroad; the other is utilized by the Painesville and Youngstown Railroad. Neither of these railroads has made cuttings in crossing the moraine, but if they had been built across the stronger portion either a steep grade or a cutting of 20 feet would have been required.

In the vicinity of Mosquito Creek only scattering knolls occur, the moraine being weaker there than at any other part of the loop that surrounds the Grand River Valley. On the uplands east of Mosquito Creek, in Mecca, Johnson, and Gustavus townships, it is well defined, having closely associated knolls 10 to 15 feet high, with shallow basins among them.

Two miles north of Kinsman, in the valley of Pymatuning Creek, is one of the most prominent hills in the moraine. It rises abruptly to a height of 80 feet, is about one-fourth mile in length and one-eighth mile in breadth. Its trend is nearly at a right angle to that of the moraine, being northwest to southeast. It is highest and most abrupt at the northwestern end, its slope having there an angle of 35° or 40°. At the southeastern end it drops down gradually and merges into a pitted gravel plain which leads down Pymatuning Creek. The peculiar structure of this hill is discussed on page 641.

On the slope west of Pymatuning Creek the drift assumes the form of low swells, seldom higher than 10 feet, but so numerous as to give it a decidedly morainic aspect. Along Pymatuning Creek, above the large knoll just described, drift knolls are rare for a couple of miles. Several drift ridges, occupying altogether a width of a mile or so, here cross the valley in an east-to-west direction, filling it so completely that the stream is compelled to wind about to find a passage through the belt. The ridges rise abruptly to a height of 20 to 30 feet, and among them are sags and basins 10 to 20 feet in depth, nearly surrounded by ridges and knolls. These ridges, continuing eastward, constitute the outer of the three lines which pass from Pymatuning Creek to Shenango River.

On the uplands, between the Pymatuning and Shenango, there are usually low knolls, 10 to 15 feet in height, some of which are rather sharp, and among them are a few basins.

There are several gravel knolls on the slope east of the Shenango River, about a half mile east of Jamestown, Pa. The largest one is 30 to 35 feet high and is surrounded by several smaller ones. Above Jamestown the knolls are 10 to 20 feet in height and of varying degrees of sharpness, from very abrupt to those of gradual slope. A few peculiar ridges were noted near Jamestown which merit individual description. One east of Kinneys Corners, in the southwest corner of Crawford County, Pa., bears some resemblance to an esker. For about a fourth mile from its western end it is only 5 or 6 feet in height and 100 feet in breadth. It here enlarges to a knoll 15 feet or more in height and perhaps 200 feet in diameter at the base. From this knoll a low ridge continues southeastward a short distance and then disappears. There are, however, for a half mile farther, in line with the ridge, occasional low, short ridges which were probably formed in connection with it. This ridge stands on a slope that descends eastward. A similar esker-like ridge was found near the Lake Shore and Michigan Southern Railroad, east of Jamestown. It is about one-fourth mile long, 20 feet high, 100 to 150 feet in width, and trends nearly west to east. A short, gravelly ridge, less like an esker than those just mentioned, was observed on John Patterson's land, 1½ miles southeast of Westford, Pa. It is less than an eighth mile in length, about 15 rods in breadth, and 20 feet in height. It is the only conspicuous drift feature in that vicinity. All these ridges contain much assorted material.

Returning to the head of Pymatuning Valley in Ohio and taking up the inner member, we find a belt of low knolls 10 to 20 feet in height leading across the uplands to the northwestern end of Pymatuning Swamp near Pennline, Pa. Among these knolls is a very prominent one which was utilized by the United States Lake Survey as a geodetic station. It stands about a half mile north of West Andover, on the east slope of Pymatuning Valley, its base being slightly below the level of the uplands. It rises abruptly about 90 feet above its western and 70 feet above its eastern base. Its longest diameter is about one-fourth mile and it trends north to south. On the knoll two basins occur near its highest point. This knoll commands a view of Lake Erie, though distant fully 20 miles. Its highest point is 1,191 feet above tide, or about 620 feet above Lake Erie.

Near Pennline, Pa., are several knolls 40 to 50 feet in height, which are nearly conical in form and very abrupt. About a mile south of Pennline two large knolls stand end to end, with a trend northwest to southeast, or about in line with the ice movement. They are fully 40 feet in height. Another knoll of similar height appears about a half mile southeast of them, while among these large knolls are numerous small ones, so that the moraine is especially well defined here. South of these knolls is a gravel plain, formed probably as an outwash from the moraine, which leads down the Shenango Valley. It contains shallow basins near the moraine, but is smooth farther south.

The most prominent knolls in the line which follows the northeast side of Pymatuning Swamp are found on the farm of Jacob Frey, 2 miles west of Linesville Two were noted which have a height of 45 to 50 feet above the swamp in which they stand. At the southeastern end of the swamp, near Hartstown, there is a cluster of large drift knolls standing on the eastern slope, which covers about a half of a square mile and includes several which are 75 to 100 feet in height. East of this group, near the residence of D. M. Calvin, there is an isolated knoll about 90 feet in height, which rises very abruptly, its base covering scarcely 5 acres. It has been opened extensively for gravel by the Erie Railway Company. It is to this knoll that White makes reference in his report on Crawford County.[1] A few low knolls occur along the east side of Crooked Creek Valley for a mile or more

[1] Second Geol. Surv. Pennsylvania, Rept. Q^4, p. 148.

south of these large ones. The divide between Crooked Creek and Pymatuning Swamp presents a series of basins inclosing lakelets, but well-defined knolls do not appear. South of these lakelets there is a smooth gravel plain leading down the valley of Crooked Creek. Being opposite the large knolls, the head of this gravel plain combines with them to reveal the position of the ice margin.

The line of drift knolls in Conneaut Valley terminates on the south in a large knoll or ridge called Faust Hill, about 2 miles northeast of Evansburg. This hill is situated on the brow of the bluff east of Conneaut Lake, its base being about 150 feet above the lake. It is 60 to 125 feet in height, the highest point being near the northern end. The trend of the ridge is nearly north to south, and its length is about three-eighths of a mile. It appears to be composed largely of gravel and cobble and is probably a short, massive esker. Between this high ridge and the Harmonsburg and Meadville road there are several low gravel ridges which vary considerably in trend. North of Conneaut Lake the valley is occupied by a series of knolls and basins. The knolls in the midst of the valley are 15 to 30 feet in height, but a few on the slopes are larger, a group southeast of Conneautville being 50 to 75 feet in height and very abrupt. Northwest of Dicksonburg a few knolls reach a height of about 50 feet, but have gentle slopes. In Conneaut Valley the sharpest knolls and ridges are on the eastern slope, but the western slope carries low swells, thus differing from the valleys of Pymatuning Swamp and Cussewago Creek, whose western slopes are nearly free from drift knolls.

The southern member of this morainic belt, which leads across from Conneaut Lake to Cussewago Creek, has low drift swells 10 or 15 feet in height, which, though feeble, present a contrast with bordering tracts on the north and south, which have scarcely any such knolls. The northern member is indicated by a gently undulating surface, the highest swells on the uplands being 10 to 15 feet high. They are conical and cover from 1 to 3 acres each. In this northern member, about 2 miles nearly due west from Crossingville, is a conical drift hill 40 to 50 feet high, covering 8 or 10 acres, and opposite this village on the west side of Cussewago Creek are two equally prominent knolls connected by a low ridge; the northern one rises very abruptly to a height of 40 to 50 feet, and covers only about $1\frac{1}{2}$ acres; the southern one is as high, but covers 3 or 4 acres. These are well shown on

the Girard topographic sheet. South from Crossingville the east side of Cussewago Creek is characterized by numerous drift knolls, but the western slope and part of the valley bottom is destitute of them. The majority fall between 10 and 25 feet in height, but at Mosiertown there is a knoll fully 50 feet in height.

Between Cussewago and French creeks there are no clearly defined morainic tracts, though drift knolls 10 feet or more in height are not rare. On the borders of French Creek Valley above Saegerstown, where the stream crosses an old divide, there are a few low drift knolls among the rock hills, the majority being less than 20 feet in height. East from Cambridge there is an open valley to the mouth of Muddy Creek, but along its southeastern slope sandy knolls occur and there are numerous knolls and ridges along the east side of French Creek, above the mouth of Muddy Creek; the largest of these are 25 to 30 feet in height. As a rule, the knolls are conical or slightly elliptical, and the ridges short, one-fourth mile or less in length. One ridge, however, was observed, about a mile southeast of Millers station, which is sharp and narrow like an esker, has a northwest-southeast trend, and is nearly one-half mile long. It rises to the uplands from near the base of the eastern slope of French Creek Valley. Its height is 30 feet, more or less, and its breadth is 50 to 100 yards.

Scattering knolls 10 to 20 feet high occur on the northwest side of French Creek in northern Crawford County and along Conneautee Creek, between Cambridge and Edinboro. Above Edinboro, in the vicinity of McLane post-office, the valley is nearly filled with sharp drift knolls, the largest of which are 30 to 40 feet in height. Among them basins are inclosed. The ridges trend in various directions. Near the northern border one trends north-northwest to south-southeast, or about in the direction of the ice movement, but farther south, just west of McLane, are ridges which trend nearly at right angles with it and lie directly across the course of the creek.

On the uplands east of Conneautee Creek drift knolls are very rare, but east of these uplands, just above Waterford, in the valley of Le Boeuf Creek, the moraine is finely developed. It consists principally of a ridge that crosses the valley from west-southwest to east-northeast (the valley having a north-south direction). Its highest points are 75 to 100 feet above the flood plain of the creek. Its length is nearly a mile, and it so

nearly fills the valley that only a narrow passage along the east side is left for the creek. The breadth of this ridge is about one-half mile. On its outer slope an undulatory tract leads down to a pitted gravel plain, from which a terrace passes down the creek. The altitude of the northern end of the terrace is 20 feet, more or less, above the present flood plain. The bluffs on each side of Le Boeuf Creek in this vicinity have numerous knolls up to a level 150 feet above the creek. They are less numerous at higher altitudes, but are not rare on the uplands northeast of Waterford, between Le Boeuf Creek and Lake Pleasant. Below Waterford but few occur, either on the uplands or along Le Boeuf Creek.

Turning now to the outer member, we find along the south side of French Creek, from Mill Village eastward, a rather low tract, a mile or more in width, on which drift knolls 10 to 30 feet in height abound, and which inclose basins an acre or more in extent, depressed slightly below the base of the knolls. Near Union City larger knolls appear, some of the members of a cluster a mile or so northwest of the town being 60 to 75 feet in height. East of Union City there are knolls 30 to 50 feet or more in height, with intervening sags and sloughs. The knolls here occur both in the valley of East French Creek and on the uplands to the north. About 2 miles northeast of Union City, near the Beaver Dam road, there is a knoll about 75 feet high which covers 8 or 10 acres. A short distance northeast from this knoll the moraine crosses a high ridge, upon which its undulations range from 10 to 40 feet. North of Beaver Dam it crosses, in a southwest to northeast direction, the valley of a small stream, presenting on its outer slope a bold front, with knolls about 50 feet in height. On either side of the valley the knolls are lower, but the moraine is well defined. This valley connects the main French Creek with East French Creek, and the moraine determines the water parting in it, the drainage north of the moraine being into French Creek near Wattsburg, while that south is into East French Creek below Beaver Dam.

From this valley northeastward into New York the moraine carries many sharp hummocks, 10 to 25 feet in height, among which are small basins. At the southwest corner of New York its altitude is fully 1,700 feet, but the knolls are as numerous and sharp here as on lower lands in this vicinity.

West of Clymers, N. Y., the moraine crosses an old valley that connects French Creek with Big Brokenstraw, and here it determines the position of

the divide. On the uplands northeast of this valley the moraine is poorly defined, there being only scattering patches of hummocky drift, but in the valley east of these uplands, at and north of Panama station, it is well defined and has many sharp hummocks. The valley which the Western New York and Pennsylvania Railway follows from Clymers to Sherman, N. Y., connects French Creek with Big Brokenstraw, and in this valley, also, the moraine determines the position of the divide.

On the uplands northeast of Panama the moraine is finely developed on ridges standing 1,800 feet above tide. It consists here of sharp hummocks 15 to 20 feet high and winding ridges of similar height, the general trend of which is northeast to southwest, but which wind and interlock. Among the large knolls are lower ones 6 to 8 feet high, and an occasional sag or basin. This topography continues eastward to the border of Lake Chautauqua.

In the city of Jamestown, and for a mile or so north, there are sharp knolls, filling up the valley at the southeast end of Lake Chautauqua to a height of 125 to 150 feet above the lake, and throwing the outlet across the rocky points on the south slope of the old valley.

Returning to the inner member, which has been described as far east as Waterford, in Erie County, Pa., we find a subdued morainic topography on the uplands between Le Boeuf Creek and Lake Pleasant, with swells 10 to 15 feet high, either isolated or in groups, constituting a nearly continuous belt.

On the lowland tract that passes from the headwaters of Le Boeuf Creek and Sixmile Creek through Lake Pleasant to French Creek there is strongly morainic topography, consisting of sharp, gravelly knolls 10 to 25 feet high, among which are basins and sags. A continuous, well-defined belt exists between this tract and Lake Chautauqua, the uplands having swells 10 to 20 feet high and the valleys larger swells or knolls, among which basins are inclosed. On the North Fork of French Creek, above Lowville, a moraine-headed terrace occurs, which near the moraine has numerous pits or basins 10 to 15 feet deep, but becomes smooth and free from such depressions farther south.

Findley Lake, in western Chautauqua County, N. Y., lies in a valley a mile or more in width. North of the lake the moraine crosses the valley, and contains knolls 40 to 60 feet high, among which there are basins 10 to 20 feet in depth, with very abrupt borders. There is an open valley from

the south end of the lake to French Creek, and it is reported that in times of high water the lake discharges southward as well as northward, but the main outlet is to the north, through North French Creek.

For several miles northeast from Findley Lake the moraine is on elevated upland, and consists of scattering knolls 10 to 20 feet high, but from the valley east of Mina Corners to Lake Chautauqua knolls 20 to 40 feet in height abound. Some of these are abrupt, but the majority have gentle slopes.

On the east side of Lake Chautauqua the drift bench above referred to may be traced from near Point Whitesides down to the southeast end of the lake, but is not well developed farther up the lake shore. The surface of the drift bench is gently undulatory, with swells 5 to 10 feet high, and ranges in height from 40 feet or less up to about 80 feet above the lake. In a few places shallow basins are present, the deepest being about 5 feet.

The eastern tributaries of Lake Chautauqua have, as a rule, smooth slopes, and the uplands between the valleys of Lake Chautauqua and Cassadaga Creek carry remarkably few drift knolls.

In Cassadaga Valley a drift bench standing 40 to 50 feet above the broad bottom is conspicuous from near South Stockton down the valley 3 or 4 miles on each side of the stream, but is not well developed farther south. There is, however, a similar bench near the junction of the creek with the Chautauqua outlet, which forms a southern limit for the broad bottom. The bench at the mouth carries numerous basins, but that farther up the valley is characterized by low swells rather than basins.

The drift deposits in Mill Creek Valley are irregular aggregations, in places nearly filling the valley to a height of 60 to 80 feet above the stream, in other places merely dotting its slopes with knolls. Occasionally the knolls occur at a height of 150 to 200 feet above the valley bottom.

The drift deposits in "Farrington Hollow" rise 50 to 75 feet above the stream, and vary from sharp knolls to nearly plane-surfaced deposits. The deposits in West Conewango Valley at Hamlet are sharp, gravelly knolls 50 to 75 feet in height, but east of Hamlet the surface is nearly level.

The bench on the borders of Conewango Valley is conspicuous from Cherry Creek southward on each side of the valley as far as Kennedy. It generally stands 40 to 50 feet above the broad bottom, is gently undulating, and carries a few basins.

The knolls along Dry Brook near Rutledge are sometimes in groups, but quite as often are isolated. There are also drift ridges, a notable example being found just east of Rutledge, which leads north to south directly across the valley of Dry Brook. It is fully one-half mile long and 30 to 40 feet in height.

The knolls are less conspicuous north from Dry Brook on the east tributaries of Conewango Creek, though, as above noted, the drift is heavy in the vicinity of Leon, and has a gently undulating surface.

The uplands between Conewango and South Cattaraugus creeks carry only a few knolls, and there are but few in South Cattaraugus Valley below Maples post-office. But on the meridian of Maples morainic features appear quite abruptly on both sides and in the bottom of South Cattaraugus Valley. The knolls are large enough to be distinctly visible on hills a mile distant to the south, and are equally large to the north, being in some instances 15 to 25 feet in height. They are larger in the valley bottom than on the slopes.

The moraine is well developed toward the east from Maples as far as the present head of an eastern branch of South Cattaraugus Creek. It there blocks the valley so greatly that the former headwater part has been turned south into a tributary of Great Valley, which it enters at Ellicottville. There is a gravel outwash from the moraine forming a plain that covers perhaps 60 acres at the present water parting, and reaches to the point where the stream to the east cuts across the old col. The moraine presents a ridge or chain of knolls only 10 to 20 feet high at the west border of this gravel tract.

The moraine does not rise to the high ridge on which Plato post-office stands, which is fully 2,100 feet above tide, but sweeps around its north slope, passing within a half mile of the post-office. It carries a large number of bowlders as well as hummocks and low ridges of drift.

Eastward to the head of Ashford Hollow the moraine presents numerous low hummocks 5 to 10 feet high. These dot the slopes and bottom of the hollow for over a mile from its head. In the interval between Ashford Hollow and West Valley the knolls are less sharp, but the drift is heavy and fills up depressions among the rock ridges sufficiently to cause some changes of drainage.

In West Valley the moraine forms a water parting which is apparently

farther north than the old divide. Immediately south of the moraine there is a valley with broad bottoms, known as the Beaver Meadow, which received an outwash from the moraine and now has southward discharge through a narrow gap into Great Valley Creek at Ashford Junction. The moraine in the valley north from Beaver Meadow carries only low hummocks seldom more than 10 feet in height.

The moraine is well defined on the ridge east of West Valley, but its knolls, like those in the valley, are small and rather sharp. The knolls become larger upon passing eastward to the Lime Lake outlet, but are not so closely aggregated. There was a line of discharge for glacial waters along a gravel plain leading from Lime Lake southward past Machias into Ischua Creek and thence to the Allegheny. At the head of this gravel plain there are small basins 15 to 20 feet deep, and also the large basin occupied by Lime Lake.

About 1½ miles northeast of Lime Lake a group of sharp drift knolls appears on the crest and slopes of a hill of shale. There is another shale hill south of this one whose surface is smooth and contrasts strongly with that of the moraine-crowned hill. Basins and low swells abound between this group of hills and Sandusky, occupying a strip 2 or 3 miles wide, the south border being about 1½ miles south of Sandusky. It is not uncommon to find basins on the slopes and tops of the swells as well as among them.

Between Sandusky and Eagle village the moraine, for 2 or 3 miles, carries many small knolls 10 feet or less in height, among which are shallow basins. A sharper morainic topography then sets in with knolls which have slopes of 20° to 30°, among which are many basins. This sharp morainic topography occupies the reentrant angle west of Eagle and extends as a spur northward 5 or 6 miles through eastern Arcade Township into southeastern Java. Some of the most prominent knolls are 60 to 75 feet high. A group of such knolls appears west of Eagle at an altitude of over 2,000 feet. From the reentrant angle near Eagle there is a strong moraine for about 3 miles eastward to an esker in southern Eagle Township.

There seems to have been a slight outwash from the moraine south of Eagle into the headwaters of Clear Creek. There is a gravelly plain at the south border of the moraine which grades up into the moraine through a series of low swells among which are shallow saucer-like depressions. The head of the gravel plain stands about 1,940 feet above tide, as

determined by barometer from Eagle station. It is one of the highest moraine-headed terraces in the eastern United States.

The esker in southern Eagle Township stands on still higher ground, its altitude being about 2,000 feet. It has a length of 1½ miles, a width of 200 feet or less, and a height of 8 to 10 feet. The southern terminus is just north of the line of Wyoming and Allegany counties. The esker lies near the north-to-south center road of Eagle Township, and for about a half mile the road follows it. At the north end it consists of two converging ridges, each of which starts in the plain north of the moraine. East of this esker there is nearly plane-surfaced drift, while west of it, as above noted, there is a strong moraine.

It is nearly 2 miles from the south end of the esker to the point where the moraine sets in again in strength. In this interval many bowlders and an occasional knoll appear. In eastern Centerville and western Hume townships, Allegany County, the moraine consists of sharp gravelly knolls 10 to 30 feet in height, among which small, deep basins are inclosed. The slopes of the largest knolls are indented and carry basins. The moraine is finely developed between Town and Cold creeks, and thence down Cold Creek Valley to the Genesee. It comes out to the Genesee on a drift bench standing nearly 200 feet above the river. This is somewhat below the bench farther south which Fairchild has interpreted to mark deposition in a glacial lake,[1] but it may be a reduction of that bench. The drift bench immediately west of Houghton station is by aneroid 1,360 feet above tide, and is dotted with drift knolls 10 to 25 feet in height.

The moraine which leads from near Machias eastward past Fairview to the Genesee River at Caneadea is not, on the whole, so strong as the moraine just described, and is more irregular in topography.

West of Machias and also south of that village, along Ischua Creek, the moraine carries many basins among the knolls. The knolls are generally 15 to 20 feet in height, though many are only 5 to 10 feet. There is south of the moraine along Ischua Creek a well-defined terrace standing about 60 feet above the stream, but it is doubtful if this terrace is a correlative of the moraine, for the morainic knolls extend down below its level, as if the terrace had been eroded before the moraine was formed. This being true, the moraine seems to mark a readvance of the ice sheet;

[1] Glacial Genesee lakes, by H. L. Fairchild: Bull. Geol. Soc. America, Vol. VII, 1896, pp. 423–452, especially pp. 436–438.

and as it drops down in Ischua Valley about to the level of the terrace which has its head in the Cleveland moraine, it seems to be not greatly different in age from that moraine.

The east bluff of Ischua Creek presents an interesting contrast between the moraine-covered and the nonmorainic parts near Machias Junction. For several miles south from the moraine the face of the bluff is very regular, but where the moraine crosses it is wavy and indented by basins. The thickness of the drift in this part of the moraine seems to be but 10 to 25 feet, varying with the height of the knolls, but it is sufficient to greatly modify the appearance of the face of the bluff.

From Ischua Creek eastward 2 or 3 miles, the moraine carries numerous sharp hummocks and basins; knolls covering but one-half acre being sometimes 15 to 20 feet high. It is much of the way on a slope descending northward, and the outer or southern part sometimes stands 75 to 100 feet above the inner or northern part. South of Elton it reaches an altitude of about 1,900 feet above tide.

The moraine is very weak from the meridian of Elton eastward to Farmersville station, but from that point to Fairview, along a tributary of Cattaraugus Creek, there are heavy drift accumulations greatly choking the valley. There are also a large number of bowlders. The knolls are not so sharp, however, as in the vicinity of Machias. North and northeast of Fairview on an elevated upland (2,000 feet or more) there are sharp knolls 20 to 30 feet high, and among them are large numbers of bowlders. This bowldery belt with its occasional sharp knolls leads southeast toward Rushford into the valley of Caneadea Creek. Upon entering this valley it becomes more prominent and fills it to a height of nearly 200 feet above the portion of the valley to the west, the crest of the moraine being about 1,600 feet above tide. The surface of this great drift accumulation is strongly in contrast with that on the bordering uplands, there being no well-defined knolls on its crest, but instead gentle undulations. It is probable, as suggested by Fairchild,[1] that this moraine held a lake in the part of the Caneadea Valley west of it for some time after the ice withdrew. The outlet is across the rock points along the south side of the old valley. The moraine was probably laid down in water, and this may account for the absence of sharp knolls.

[1] Glacial Genesee lakes, by H. L. Fairchild: Bull. Geol. Soc. America, Vol. VII, 1896, p. 451.

THICKNESS OF THE DRIFT.

The thickness of the drift varies greatly along the line of the Cleveland morainic belt, possibly more than in any of the moraines yet described. The moraine crosses tributaries of the Lake Erie Basin, which have received a filling of several hundred feet, while on the high ridges between these valleys there is usually a very thin coating of drift. Well sections in Cleveland along the old line of the Cuyahoga show drift extending about 500 feet below the level of Lake Erie, while the drift filling near the south border of the city reaches a level more than 200 feet above the lake. There is thus possibly more than 700 feet of drift in places where the deepest part of the old channel lies beneath uneroded parts of the valley filling, and probably an even greater amount in the Conewango Valley, which constituted the old northward line of discharge for the upper Allegheny. This valley is filled to a level about 700 feet above the surface of Lake Erie, yet its floor at the place where the moraine crosses was probably but little, if any, above the lake level. The borings are not, however, sufficiently deep to test this matter. The borings in Cattaraugus Valley, about 5 miles north of Maples, show a rock floor more than 700 feet below the level of the South Cattaraugus Creek bottom at the place occupied by this moraine. Aside from the valleys just noted, a drift filling of 300 to 500 feet or more may be expected in the valleys of Chagrin River, Grand River, Pymatuning Creek, Pymatuning Swamp, Conneaut Creek, Cussewago Creek, French Creek, Lake Chautauqua, Cassadaga Creek, and Genesee River.

Of this large amount of drift in the valleys the greater part was deposited at an earlier date than the Cleveland morainic belt. The amount deposited in connection with the moraine probably exceeds by only a small amount the relief of the moraine above the portions of the valleys outside. Where outwash occurred in notable amount there may have been considerable filling in the part of the valley outside the moraine. But in general, it may be stated that the morainic filling in the valleys does not exceed 100 feet, and is, therefore, but a small fraction of the total filling.

The amount of drift deposited on the uplands in connection with this moraine may usually be estimated from the relief of the moraine, and this, as indicated above, ranges from 10 feet or less up to about 50 feet.

STRUCTURE OF THE DRIFT.

The upland portion of this morainic belt consists largely of a very stony till from which much of the clay seems to have been removed. Small stones, 3 inches or less in diameter, are often so numerous as to give the drift a gravelly appearance, yet there seems to be little stratification or definite bedding, and, as a rule, the stones are not much rounded by water action.

In the Ohio part of this morainic belt the upland drift is, on the whole, more clayey than in the Pennsylvania and New York portions, and often presents the appearance of the typical till of the plains to the west.

As indicated in the descriptions already given, there are many gravel knolls and ridges on the uplands, but they do not form so conspicuous a feature there as in the valleys.

In the valleys there is usually at the surface a partially assorted sandy and gravelly drift extending down at least to the level of the base of this moraine. In the knolls there is often a much disturbed and irregular bedding. This may be due in part to settling of the beds since their deposition, but in some places it appears to have been produced by the movement of the ice sheet. The outwash from the moraine is generally a fine gravel or sand, showing a moderate current.

Below the level of the base of the moraine the valleys have been filled with silt and fine sand, some of which is so compact that it is found difficult to obtain a well. This silt is apparently in large part a water deposit, made in lakes that were held between the ice front and divides to the south.

Bowlders of granite and other crystallines abound all along the moraine, and are, on the whole, much more numerous than on the bordering nonmorainic tracts.

The largest and most interesting exposure found in this moraine is the gravel pit opened by the Youngstown branch of the Lake Shore and Michigan Southern Railway, 2 miles north of Kinsman, Ohio, in a large knoll previously mentioned. This knoll is opened from end to end along its western side, and its excavation extends nearly to the central portion. Talus obscures portions of the slope, so that contact lines between beds are not readily distinguishable. A mass of cobble and gravel constitutes the body of the highest part of the hill, whose strata sag beneath the high part

and outcrop on the northern slope. Beneath this gravel-cobble mass, both north and south of the highest part of the hill, there is fine sand. The strata on the north dip southward, while those south of the cobble are crumpled or arching. South of this sand is a mass of horizontally bedded cobble-gravel, succeeded on the south by fine sand, also horizontally bedded, which grades into a clay at bottom. The extreme southern end of the hill is cobble-gravel, which connects with a pitted plain underlain by coarse gravel. Such a complete section as this will probably be of value in working out the precise method of origin of knolls of this class, but as yet its significance is not clearly understood.

In the south part of Bemis Point, on the east side of Lake Chautauqua, there is a railway gravel pit in a bench standing about 50 feet above the lake that exposes beds which bear a striking resemblance to the foreset and topset beds of a delta, and it seems probable that they were formed by water escaping from the ice sheet into a lake. The pit is about 20 feet in depth and more than 100 feet in length. The lower 12 or 14 feet presents beds of gravel, having a sharp southward dip, while the surface portion, 6 or 8 feet in depth, shows horizontal bedding that cuts across the truncated ends of the underlying inclined beds. Well sections at the village of Bemis Point show the drift structure at lower levels than at the gravel pit. George Scofield has a well on ground about 40 feet above Lake Chautauqua which penetrated sand and gravel for perhaps 60 feet. Below this to a depth of 190 feet the well is in a blue clay, free from pebbles, and was abandoned without reaching the bottom of the clay A still deeper boring at the Cottage Hotel is reported by the driller to have passed through about 8 feet of surface gravel and then 40 feet of sandy material, when a blue clay was struck, which he penetrated to a depth of 310 feet from the surface without reaching its bottom. This boring was on ground scarcely 20 feet above Lake Chautauqua.

There is a large gravel pit in a knoll at Sandusky, New York, 60 feet or more in depth at the highest part of the knoll and about one-eighth mile in length. It extends from the top to the bottom of the knoll, but at the time of the writer's visit the talus obscured much of the face. It shows an intricate series of gravel, sand, and finer material, some beds being of very fine silt. The bedding is wavy, with variations in level amounting to several feet in a distance of only a few yards. Many smaller excavations were

noted, but they do not present features much different from those already mentioned. Commonly, they show horizontal bedding, though it is often slightly wavy. Near the border of a knoll the well-defined beds usually give place to poorly assorted material with ill-defined bedding planes.

The well sections have thrown considerable light upon the depth and structure of the drift both on the uplands and in the valleys. A few of these will be next considered.

On the portion of the moraine lying west of the Cuyahoga the wells usually penetrate a typical till, such as appears in plains to the west. They have in some cases reached rock at 20 to 25 feet, but in other cases have penetrated to a much greater depth without reaching the bottom of the drift, the supply of water being from thin beds of sand associated with the till.

At Randall, east of the Cuyahoga, a well 96 feet deep, on Chris. Emery's farm, struck stone at bottom thought to be bed rock. It was through ordinary blue till nearly the whole depth. A prospect boring for coal was attempted near Randall some years ago by Otis Forer, which penetrated fully 100 feet of drift.

Gas borings in the Chagrin Valley, near Gates Mills, Orange, and Wilsons Mills, pass through from 120 to over 200 feet of drift. The lower portion of the drift is a fine silt or blue clay, but the upper portion is rather stony.

In the valley of East Chagrin River, near the Chardon and Cleveland road, a farmhouse well penetrated 161 feet of drift. For 100 feet the drift is mainly till, below which it is a fine sand.

At Wallace Weaver's, 2 miles west of Chardon, there is a flowing well which obtains its water from the sandstone, but it penetrated 30 feet of drift before entering rock.

In Hampden Center the drift is mainly till, and several wells strike rock as follows: William Cutt's, at 35 feet; E. Thayer's, at 36 feet; O. R. Chamberlin's, at 35 feet; post-office well, at about 60 feet.

In Grand River Basin the wells usually penetrate a large amount of blue clay which is reported to carry but few pebbles. Much of it may be water-laid silt, deposited in a lake outside the ice sheet, but the surface portion as deep down as the base of the moraine seems to be ordinary till. The wells, as shown in the table below, have in some cases penetrated

more than 200 feet of drift, and in one case reached a depth of 222 feet without entering rock. There are places in the basin where rock is near the surface, the deep part of the valley being much narrower than the basin.

No well records showing a large amount of drift were obtained along the line of this moraine in northwestern Pennsylvania. Ordinarily water is found at shallow depths in the valleys, so that there has been little need for deep boring in them, while on the uplands wells usually strike rock at moderate depth. The wells at Bemis Point, in the valley of Lake Chautauqua, referred to above, and a few in Conewango Valley constitute the only records of deep wells which have been collected along this moraine in western New York. Of those in Conewango Valley one near Randolph reached a depth of 280 feet, one near Rutledge 314 feet, and one near Dayton 330 feet without entering rock. They penetrated blue clay nearly the whole depth. Deep wells in Cattaraugus Valley, north of the Cleveland moraine, are discussed on a later page.

The deepest well records obtained near Cassadaga Valley are in Mill Creek Valley at Sinclairville, about 2 miles from the junction with Cassadaga Creek. Two wells on a drift bench standing 60 feet above the creek reach depths of 105 and 125 feet without entering rock. They are mainly through blue clay.

The following table shows the thickness and to some extent the structure of the drift in many other wells on or near the moraine. It includes wells in the Grand River Basin that are at some distance north of the moraine. Where the plus sign is affixed rock was not reached. The minus sign is used where precise depth to rock is not known. Where owners' names are not given there are usually several wells at about the same depth which gave similar results.

Table of well sections.

Owner and location.	Depth of drift.	Remarks.
	Feet.	
W. J. Johnson, east of North Linndale, Ohio	34	On north slope of moraine; mainly till.
D. Gilmer, near Wilson Mills	200	Gas well enters rock at about 200 feet; others near by at 120.
C. Sheldon, at Orange	120	Gas well enters rock at 120 feet.
Mr. Robinson, north of Chardon	72	Near Big Creek; no rock struck.
H. Gardner, west of Hampden	33	Strikes rock at 33 feet.
L. Foedler, northwest of Hampden	40	Strikes rock at 40 feet.
M. M. Ballard, east of Hampden	41	Strikes rock at 41 feet.
S. S. Tucker, Huntsburg	35	Till 20 feet; sand 8 feet.
Julius Knoeffles, West Farmington	70	Mainly blue till.
H. A. Houghton, south of Farmington	210	In Grand River Valley.
J. M. Harwood, near Farmington	222+	In Grand River Valley.
Thomas Crocker, near Farmington	80	In Grand River Valley.
H. W. Schaffer, near Farmington	160	Mainly blue till, few pebbles.
Charles Pierce, near Farmington	145	In Grand River Valley.
J. Hanna, north of Farmington	70	In Grand River Valley.
Mr. Griffith, north of Farmington	70−	Less than 70 feet to rock.
H. Reynolds, north of Farmington	100+	Rock not struck.
Cheese factory, Mesopotamia Center	130+	Mainly blue clay.
Name not learned, Mesopotamia Center	208	Reported by driller, Mr. Dayton.
Fred Beckwith, Windsor Corners	54+	Rock not struck.
Vinton Way, near Grand River, in southern Ashtabula County.	170+	Mainly blue clay, pebbleless.
C. Haines, Bloomfield Center	85	East slope of Grand River Valley.
G. E. Haines, Bloomfield Center	75+	Mainly till.
Several wells, Bristolville	13–40	East slope of Grand River Valley.
Several wells, Champion Center	30+	In Grand River Valley.
Edward Baldwin, east of Mecca	21½	Mainly till.
Eugene Root, northeast of Mecca	38	Mainly till.
C. J. Bryant, northeast of Mecca	62+	Till and sand.
R. P. Gilmore, southwest of Gustavus	90+	On upland.
J. B. Scott, southwest of Gustavus	90+	On upland.
M. D. Cowdens, southwest of Gustavus	62+	On upland.
Dwight Moore, northwest of Gustavus	40	On upland.
Near Evans's store, Barclay post-office	70−	Rock at less than 70 feet.
Cheese factory, Barclay post-office	50−	Rock at less than 50 feet.
G. W. Burrill, Kinsman	99+	In valley.
Fair grounds, Kinsman	137+	In valley.
Henry Burnham, Kinsman	15	In valley.
Mr. Muir, Wayne Center	30	On upland.

Table of well sections—Continued.

Owner and location.	Depth of drift.	Remarks.
	Feet.	
Mr. Babcock, north of Wayne Center	20	On upland.
Mr. Bartholomew, north of Wayne Center	42+	Mainly till.
Mr. Andrews, north of Wayne Center	23	On upland.
Mr. Watts, south of Cherry Valley	46+	On upland.
H. W. Holcomb, southwest of Andover Center	20	On upland (1,160 feet above tide).
Aaron Tuttle, southwest of Andover Center	80+	In Pymatuning Valley.
Aaron Tuttle, southwest of Andover Center	45+	Gravel, blue till, sand.
Williamsfield Center, several wells	25–30	Gas and oil from rock at 50–100 feet.
H. Waters, north of Williamsfield Center	40	On uplands.
James Marvin, north-northeast of Williamsfield Center.	40+	On uplands.
James Martin, northeast of Williamsfield Center.	57+	Mainly till.
Moses McArthur, south of Westford, Pa	50	On slope.
Linesville, oil boring	31	On slope.
Mr. Williams, north of Linesville	20	On uplands.
Cheese factory, Evansburg	90+	In Conneaut outlet.
C. J. McDill, Evansburg	85+	Near Conneaut outlet.
Southwest part of Evansburg	60+	Several wells.
Mr. Davenport, west side of Conneaut Lake	30	Between lake and west bluff of valley.
Dr. Bean, Harmonsburg	45+	In valley.
Mr. McDowell, near Dicksonburg	71+	On slope.
A. A. Gallup, near Dicksonburg	64+	On slope.
Mr. Schofield, Conneautville	187	Penn. Sec. Geol. Surv., Q^4, p. 32.
J. W. Rice, east of Harmonsburg	20	On slope.
D. W. Dean, east of Harmonsburg	30+	On slope.
Levi Putnam, east of Harmonsburg	6–18	On uplands.
Cheese factory west of Meadville	18	Altitude about 1,350 feet above tide.
Mr. S. Sheldon, northeast of Springboro	40+	On uplands.
Eureka Hotel, Saegerstown	35	In French Creek Valley; mainly gravel.
J. W. Lang, Venango	65	In French Creek Valley; mainly sand.
Isaac Pifer, Venango	60	In French Creek Valley; mainly sand.
Mr. Nye, at McLane	40+	On a knoll.
Mrs. M. Oaks, at Waterford	115+	On the terrace.
Union City, several wells	20	In valley.
V. Bently, northeast of Union City	53	On slope.
S. Phelps, north of Wattsburg	37+	In North French Creek Valley.
Peter Montague, Mina Corners, N. Y	55	On uplands.
Henry Ottaways, east of Mina Corners, N. Y	100+	On lowlands.
North Clymer, N. Y., several wells	35+	In valley.

OUTER BORDER PHENOMENA.

The terraces and gravel plains associated with this morainic system are all that will here be treated, the other drift features having already been considered. The discussion begins at the west and proceeds eastward.

On the Cuyahoga no well-defined terraces were observed. There was no doubt a discharge from this valley westward into Lake Maumee, near the south border of the moraine.

In the Grand River Valley the plain south of the moraine has some silt and some assorted material at surface, but the slight exposures which occur show the drift to be principally till, probably a ground moraine of the same age as moraines farther south.

On Pymatuning Creek, a tributary of the Shenango, there is a well-defined moraine-headed terrace, consisting of a pitted gravel plain extending from the moraine southward to Kinsman, a distance of 2 miles, below which it is nearly free from pits. These small basins occupy an acre, more or less, each, and have very abrupt, wall-like borders. The majority of them appear to be filled up considerably with peat, but are still depressed from 5 to 10 feet, or even more, below the bordering gravel plain.

On Shenango River no moraine-headed terrace was discovered, but much assorted material lies along it below the moraine, and the stream in this vicinity may now be occupying its glacial flood plain.

On Crooked Creek, near Hartstown, are pits and small lakes bordered by nearly level topped gravel deposits, which lead southward into a smooth-surfaced plain. This stream seems to be flowing near the level of the glacial flood plain for several miles below its source.

In the Conneaut Valley there is an extensive marsh, leading from Conneaut Lake along its outlet nearly to French Creek. This is, perhaps, a glacial flood plain, for the moraine, crossing the valley at the north end of the lake, rises but little above the marsh. The lake bottom itself is a great pit in this marsh at the point of connection with the moraine. On the southeast border of the lake there is a bench about 50 feet high, having a few feet of till at surface and gravel below, which was probably formed before the ice sheet made its last advance. Remnants of a terrace-like bench, which may be its continuation, occur along the borders of the marsh between Conneaut Lake and French Creek. They are, in some cases at least, not covered with till.

On French Creek there is an extensive plain of sandy gravel, leading from the moraine near Saegerstown southward, and extending beyond Meadville. It is only 15 to 20 feet above the level of the creek, and consequently is much below the level of the drift deposits of the outer moraine, where it passes through them near Cochranton. This does not make a clear connection with the moraine at Saegerstown, and may simply represent a postglacial flood plain of French Creek.

On Conneaut Creek, above Edinboro, there is an extensive plain but little above the level of the stream, which heads abruptly at the inner member of this morainic belt near McLane. Being low and swampy it affords no exposures showing its structure, but its surface is gravelly.

On Le Boeuf Creek, at Waterford, this inner member connects with a terrace which leads down the creek. There are many small basins in the terrace at its head, and Lake Le Boeuf occupies a large one, nearly a square mile in extent.

Lake Pleasant Valley was not examined below the lake. Whether or not the inner member has a terrace here has not been ascertained. On North French Creek, the next valley to the east, this member has a terrace which heads a mile or more north of Lowville in the moraine, and has there many pits or small basins, some of which have abrupt, wall-like margins. This terrace follows the stream southward to French Creek, at Wattsburg, maintaining a height of 20 feet or more above its present flood plain. The outer member, which passes south of Wattsburg, has a moraine-headed terrace leading south through Beaver Dam. It stands 15 to 20 feet above the present flood plain of the small stream that traverses this valley.

In southwestern New York the outer member has a gravel plain in a valley southwest of Clymers, which connects French Creek with Big Brokenstraw, and one heading in another valley, near Panama station, also connects French Creek with Big Brokenstraw. In neither place is the gravel plain much above the level of the present flood plains of the small streams which occupy the valleys. The inner member has a glacial outlet into French Creek Valley from Findley Lake, the lake now occupying a portion of this outlet.

Along the outlet of Lake Chautauqua there is a pitted gravel plain outside the moraine, remnants of which are conspicuous in the vicinity of Falconer. Its height is only 50 to 60 feet above the outlet, or scarcely

half that of the morainic filling. The pits are in some cases fully 20 feet in depth, though usually much less. Excavations in and near Falconer show the material to be largely gravel and fine sand, there being but little coarse gravel and cobble.

This gravel plain has a continuation up Conewango Creek Valley above the junction with the Chautauqua outlet, occupying the valley as far up as Kennedy. It stands about 60 feet above Conewango Creek and carries numerous basins. The basins are usually shallow, 3 to 5 feet in depth, but occasionally reach 10 feet. This pitted gravel plain seems to have been formed by waters from Cassadaga Creek as well as from Conewango Creek, for it fits about the southern end of the low plain in Cassadaga Valley. As indicated above, neither Cassadaga Creek nor Conewango Creek has a well-defined moraine at the head of the gravel plain, such as appears in the Lake Chautauqua outlet at Jamestown.

The lines of outwash farther east, on a tributary of Great Valley Creek near Plato, on Big Meadow, on Ischua Creek near Machias, and at Eagle have already been discussed. The strongest of these are on Big Meadow and on Ischua Creek, each being fully a half mile in width; the others were apparently weak lines of discharge.

In the Genesee Valley a lake was formed, which, as indicated on p. 201 et seq., had its discharge to the Allegheny River past Cuba, N. Y.

A word of explanation seems necessary in support of the opinion, already several times expressed, that the lakes along the outer margin of the moraine occupy basins which owe their origin to the ice sheet. These lakes have considerable depth (portions of Conneaut Lake being 100 feet deep), yet they are so situated in reference to the moraine, being in an open valley on its outer border, that they should have been filled with an outwash from the ice sheet, unless some obstacle not now present opposed this filling. No other obstacle is known but ice. It therefore seems probable that these lakes, and others of similar position, owe their existence to the presence of large masses of ice in the vicinity of or just below the ice margin. The smaller basins of pitted outwash aprons and moraine-headed terraces are also supposed to owe their existence to the presence of large masses of ice in the flooded outer border tract. In most cases there was probably no transportation and grounding, but simply a persistence of the ice there after it had melted away from adjacent parts of the valley.

Basins lying within the moraine, such as that of Lake Chautauqua, seem also to mark places where the ice remained for an exceptionally long time. Many of the lake basins in the moraine are, however, due to irregularities in the drift surface which may not be easily explained.

INNER BORDER PHENOMENA.

Between the Cleveland morainic belt and the next later morainic system there is a tract with smooth or very gently undulating drift surface and with rarely a knoll worthy of note; the tendency toward aggregation in knolls being much less than in the district outside the Cleveland belt.

No striæ have been observed except in Wayne Township, Ashtabula County, Ohio, where a sandstone is glaciated. Their inconspicuousness is due probably to the rapid weathering of the shale which underlies the greater part of the district.

The thickness of the drift in the valleys is known to be very great, for wells seldom reach the rock, but the uplands and slopes are thinly coated with drift, the depth seldom exceeding 25 feet.

POSTGLACIAL RIDGES.

A network of recently formed ridges in Cuyahoga shales occurs in western Trumbull County, Ohio, near the "Old Brick hotel," about 2 miles northwest of Braceville. They are on a lowland tract, the greater part of which is very level, but at the northwestern end of the system of ridges there is an ascending slope on which one of the ridges is developed. The area over which they were observed scarcely exceeds 10 acres, but since a complete tracing of them was not attempted they may have a greater extent. Their usual height is 3 to 6 feet, and their breadth about 100 feet. In form they bear a striking resemblance to low eskers, but in structure they are very different, being composed of rock instead of drift. The shales which constitute them arch with the surface of the ridges, and become horizontal on each side within a few feet of the base of their slopes. The cross section of one of them is well shown on the north side of the State road, where an artificial ditch is opened through it. The ridges are usually joined together, but a single isolated one being observed. They meet at various angles, but are all nearly straight. The prevailing trends are north to south and east to west, but some have a trend N. 30° W. to S. 30° E. The one

mentioned above as lying on an ascending slope has this trend. Read describes ridges that are apparently similar to these, and considers them due to the movement of the ice sheet across the strata.[1] Ridges of this class have also been observed by Gilbert along the south shores of Lake Erie and Lake Ontario, and are considered by him postglacial, the result of expansion of the strata after the withdrawal of the ice sheet and its attendant cold water.[2] The Braceville ridges, like those observed by Gilbert, are thinly covered with drift, and were plainly formed subsequent to its deposition. They show no dependence upon glaciation, being directed toward all points of the compass. The phenomena described under this title may be of common occurrence, but have been rarely observed. It is thought that as evidence of recent changes in the rock strata their importance is great.

RELATION OF THE CLEVELAND MORAINE TO LAKE MAUMEE.

This morainic belt appears to have been completed near the time when the glacial Lake Maumee dropped from its highest level to the level of the Second or Leipsic beach, and is therefore contemporaneous with the closing part of the highest lake stage. The relations are considered at some length in the discussion of the Maumee beaches (Chapter XIV).

LAKE ESCARPMENT MORAINIC SYSTEM.

Under this name is discussed a system of moraines which covers part of the brow and much of the face of the Lake Erie escarpment from near Cleveland, Ohio, eastward into New York. It consists of overlapping moraines or drift ridges which set in one after the other in passing from west to east. In cross section there are seldom more than two ridges, and in parts of its course but a single ridge is found. The combined belt in western New York has been referred to by the writer as the Dayton moraine,[3] but it seems preferable to substitute the name Lake Escarpment system, and to give names to each morainic ridge.

The ridge which was formed first and which extended farthest west has been known for some years as the Euclid moraine, its western terminus being near Euclid, Ohio, a village 10 miles east of Cleveland. This is overlapped by a later ridge from near Painesville, Ohio, eastward, which

[1] Geology of Ohio, Vol. I, 1873, pp. 490, 507.
[2] Proc. Am. Assoc. Adv. Sci., Buffalo meeting, 1896.
[3] Am. Jour. Sci., 3d series, Vol. L, 1895, p. 8.

will be termed the Painesville moraine. Near Ashtabula, Ohio, a third ridge sets in, to which the name Ashtabula moraine may be applied. A short distance west of Girard, Pa., a fourth ridge appears, which will be known as the Girard moraine. In western New York later moraines appear, but as none of them are coalesced with this morainic system west of the interlobate moraine that occupies the high divide west of the Genesee they can scarcely be included in it, and are accordingly treated separately. In the interlobate belt this morainic system and some of the later moraines become blended and form a spur northward along the high divide to its northern limits west of Attica. They seem also to be combined into a single broad belt from this interlobate eastward to the Genesee Valley.

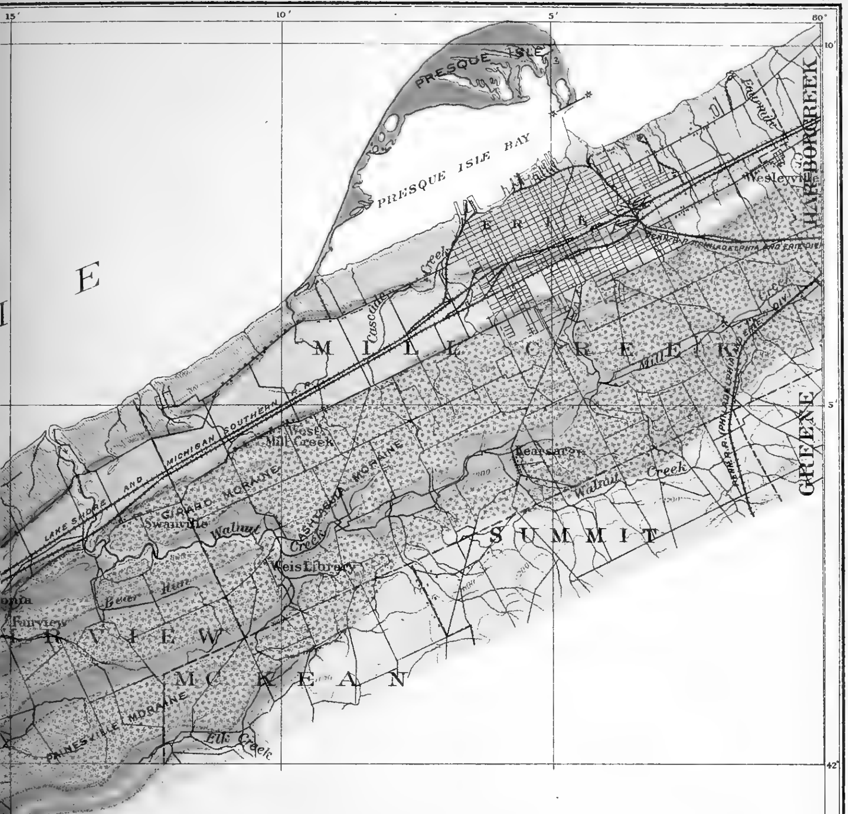
The position and relation of each of the members of the lake escarpment system may perhaps be best outlined by following the system through from west to east.

DISTRIBUTION.

The westernmost appearance of this system seems to be in a weak till ridge which lies along the north side of Euclid Creek east of the village of Euclid, and which comes to Chagrin River about 2 miles south of Willoughby. The ridge is scarcely strong enough to admit of easy tracing and the depth of drift along it is remarkably slight, the rock being struck usually at only 15 to 20 feet; yet this seems to be the natural line of continuation of a better defined morainic ridge which sets in east of Chagrin River. From Chagrin River eastward to Grand River there is a well-defined till ridge which follows the north bluff of the west-flowing part of East Chagrin River past Kirtland and comes to the south bluff of Grand River at the bend south of Painesville.

From Painesville eastward two moraines are found in the place of the one which was found west of that city. The outer, or Euclid, lies along the face of the escarpment south of Grand River, while the inner, or Painesville, follows the north side of the river and holds it in its westward course from near Austinburg to Painesville. The moraines pass the north end of the Grand River Basin without notable deflection from a direct course. The ice sheet seems to have been too thin or too weak to extend a lobe into the basin. The Euclid moraine passes south of Austinburg and East Plymouth, Ohio, forming the north bluff and determing the westward course of Mill Creek, while the Painesville moraine lies parallel with it and about 2

LAKE ER
Fairplain
Miles Grove
Wallace Junction
GIRARD MORAINE
ASHTABULA MORAINE
Girard
Elk Creek
DELTA
North Springfield
Springfield Station
Cross Station
East Springfield
Center Corner
West Springfield
Platea
SPRINGFIELD
GIRARD
ELK CREEK
CONNEAUT
Raccoon Creek
Turkey Creek
Conneaut Creek
Marsh Run
Ashtabula Creek
Cherryhill
PAINESVILLE MORAINE
ASHTABULA MORAINE
EUCLID MORAINE
FOREST BEACH
ARKONA BEACH
BELMORE BEACH
SECOND MAUMEE BEACH
NEW YORK CHICAGO AND ST. LOUIS
PITTSBURG BESSEMER AND LAKE ERIE
PITTSBURG BAR
BOUNDARY LINE
OHIO
PENNSYLVANIA
30′
25′
20′



PLEISTOCENE MAP

OF PART OF THE

GIRARD AND ERIE, PENNSYLVANIA, QUADRANGLES

By Frank Leverett

Scale

0 ½ 1 2 3 4 5 Miles

0 ½ 1 2 3 4 5 Kilometers

Contour interval 100 ft.

1900

LEGEND

Moraines

Lake Whittlesey

Non-morainic drift

Lake Warren

Beaches

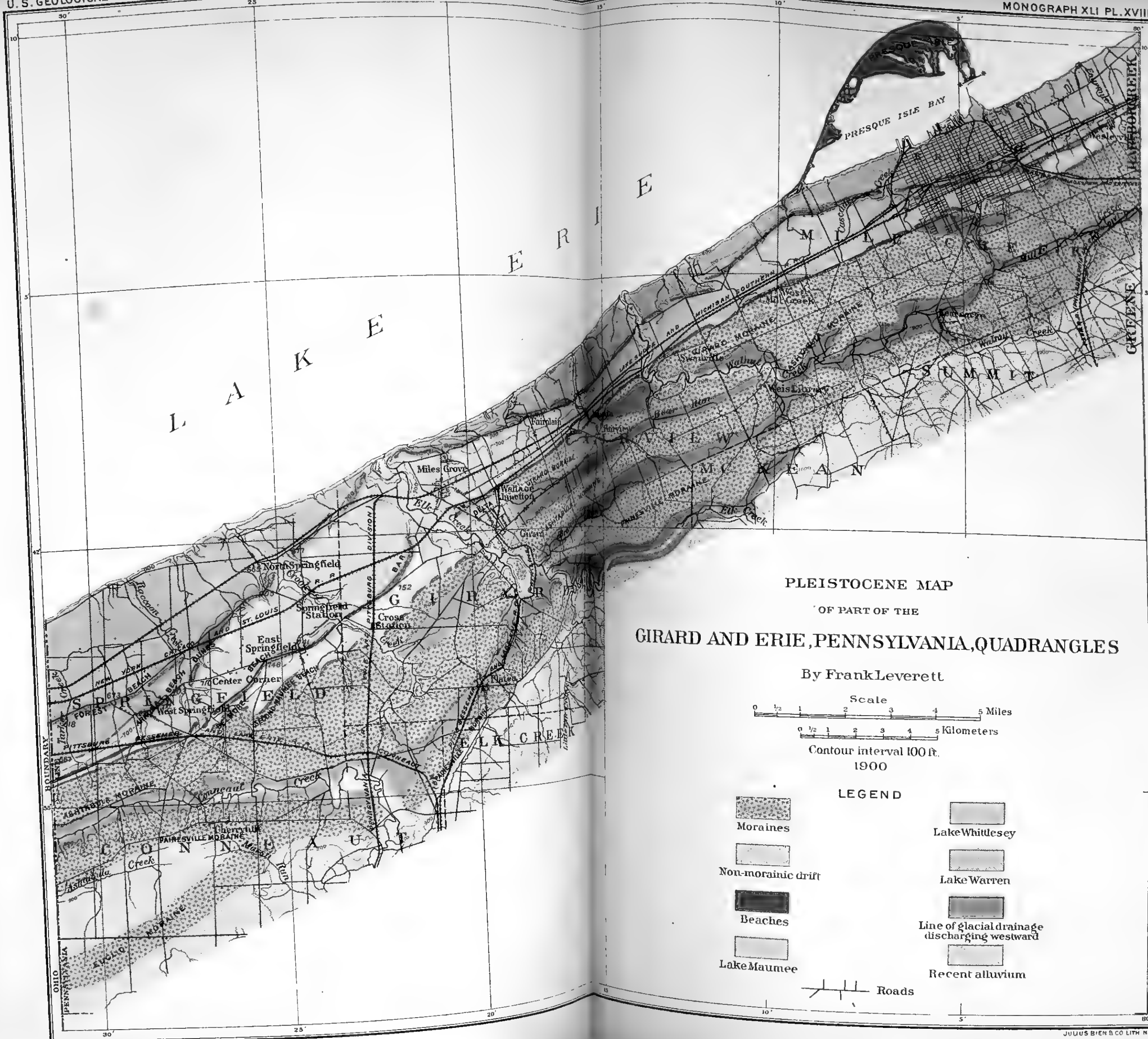
Line of glacial drainage discharging westward

Lake Maumee

Recent alluvium

Roads

JULIUS BIEN & CO LITH N.Y.



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1900

LEGEND

Moraines

Lake Whittlesey

Non-morainic drift

Lake Warren

Beaches

Line of glacial drainage discharging westward

Lake Maumee

Recent alluvium

Roads

miles distant on the north. From the bend of Ashtabula Creek at East Plymouth the Painesville moraine follows up the south side of the creek to Kelloggsville, where it crosses to the north side. The Euclid moraine lies a short distance south, near the base of the rock escarpment. East from Kelloggsville, the valley of Ashtabula Creek lies between the two moraines to their junction at the head of the creek.

A third ridge sets in at Ashtabula, causing the great oxbow bend of Ashtabula Creek, and leads eastward through Kingsville, where it crosses Conneaut Creek, and continues into Pennsylvania along the north side of that stream. It is separated from the Painesville moraine only by the valley of Conneaut Creek.

The course of each of the moraines of this system in western Erie County, Pa., is shown in Pl. XVIII. The Euclid and Painesville moraines become united at the head of Ashtabula Creek, about 6 miles east of the State line, and the united moraine crosses Conneaut Creek 1 to 2 miles north of Albion, just south of the great bend of the creek. From Conneaut Creek it follows the base of the escarpment northeastward to Elk Creek at Sterrettania, crossing Little Elk Creek near its mouth. Upon passing to the north side of Elk Creek near Sterrettania it becomes difficult in places to separate this moraine from the Ashtabula moraine, but generally a narrow sag or valley lies between the two. Mill Creek and Walnut Creek each occupy this sag for a few miles.

The Ashtabula moraine follows the north bluff of Conneaut Creek eastward to the great bend at Lexington. It there turns northeastward, passing just west of the village of Lockport (Platea station), and crosses to Elk Creek 1 to 2 miles above Girard. Upon crossing Elk Creek it turns eastward and, as above noted, is separated from the Painesville moraine by only a narrow valley-like depression. This depression apparently furnished a line of westward escape for glacial waters.

The fourth, or Girard, moraine is well defined and distinct from moraines outside of it for only a few miles in western Erie County, Pa. The western end is immediately north of Girard; but it may perhaps continue as a low water-laid moraine westward along Elk Creek to the shore of Lake Erie. The contours of the topographic sheet have suggested such a continuation.

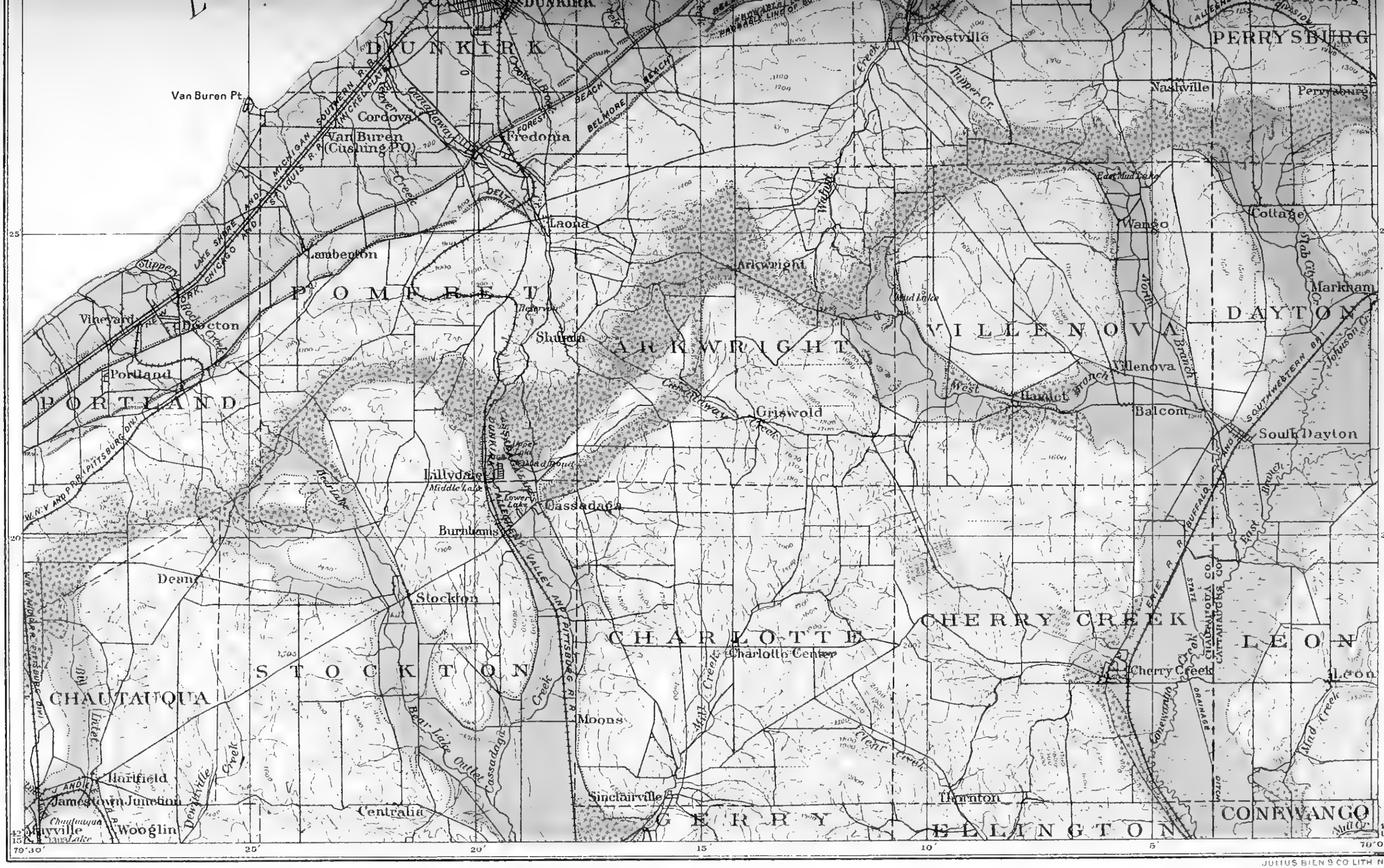
Between Cross station and Girard a range of knolls and ridges

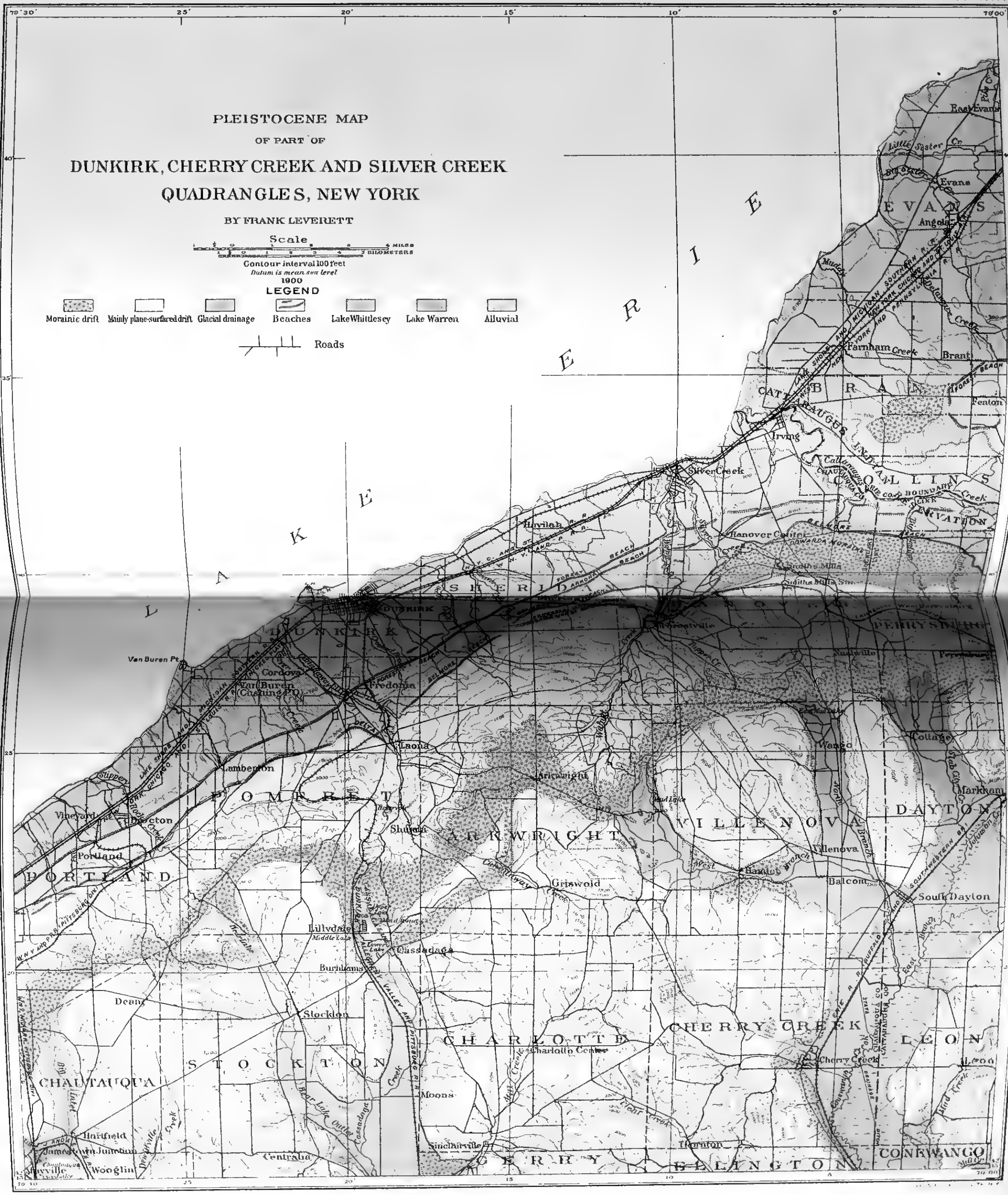
appears which is somewhat distinct from the Ashtabula moraine. It lies mainly north of the Girard and Lexington wagon road and occupies a width of scarcely one-half mile. On the outer (south) border there is a narrow gravel plain that appears to be an outwash from the moraine. This was at first thought to be a probable continuation of the Girard moraine, but an inspection of Pl. XVIII will make clear that it fits in better with the Ashtabula moraine. From Girard eastward to Swanville the Girard moraine consists of a narrow, nearly continuous till ridge, having only a few knolls associated with it. It lies north of the Girard and Erie wagon road most of the way to Fairview and south of that road from Fairview to Walnut Creek Valley, opposite Swanville. Upon crossing Walnut Creek it becomes much stronger and remains conspicuous to its junction with the morainic belt outside of it near West Mill Creek station.

From the vicinity of Erie, Pa., eastward to the north end of Lake Chautauqua, in New York, there is a single prominent moraine 1 to 3 miles in width. It follows the north side of Walnut Creek about to the meridian of Erie, and there crosses Mill Creek and follows its north side past Belle Valley, its inner border extending down to the south edge of the city of Erie. It crosses Sixmile Creek south of the village of Harbourcreek, and Sixteenmile Creek just below (west of) Grahamville. It enters New York at the bend of Twentymile Creek and follows the north side of the west-flowing portion of that creek across Ripley Township to its source in western Westfield Township, Chautauqua County, N. Y. It comes to Chautauqua Creek 3 miles south of Westfield, and nearly opposite the mouth of Little Chautauqua Creek. Throughout much of the distance from Erie to Westfield its inner border is within 1 to 2 miles south of the railway lines, and for a short distance between Northeast, Pa., and the New York line it extends slightly north of the railways. The inner border is on the whole less definite and regular than the outer, and knolls and ridges occur sparingly for a mile or two north of the main belt. An instance is found at Northeast, Pa., where there is a series of knolls and short ridges 10 to 20 feet high, standing nearly 2 miles north of the main moraine. These and other similar short ridges along the inner border of the main belt seem scarcely prominent enough to merit separate name and description.

The course of this morainic system from Lake Chautauqua to Cat-


PLEISTOCENE MAP
OF PART OF
DUNKIRK, CHERRY CREEK AND SILVER CREEK
QUADRANGLES, NEW YORK
BY FRANK LEVERETT
Scale
4 MILES
3 KILOMETERS
Contour interval 100 feet
Datum is mean sea level
1900
LEGEND
Morainic drift
Mainly plane-surfaced drift
Glacial drainage
Beaches
Lake Whittlesey
Lake Warren
Alluvial
Roads
79°30′
25′
20′
15′
10′
5′
79°00′
40′
35′
30′
L A K E E R I E
E V A N S
B R A N T
C O L L I N S
East Evans
Evans
Angola
Farnham
Brant
Fenton
Irving
Silver Creek
Hanover Center
Smiths Mills
Smiths Mills Sta.
Hayilah
Little Sister Cr.
Big Sister
Delaware Creek
Muddy
Farnham Creek
Cattaraugus
BOWANDA MORAINE
FOREST BEACH
ARKONA BEACH
BELMORE BEACH
Walnut Cr.
Silver Cr.
Big Indian
Little Indian
RESERVATION
L.H.


DUNKIRK
PERRYSBURG
Forestville
Nashville
Perrysburg
Van Buren Pt.
Cordova
Van Buren (Cushing P.O.)
Fredonia
Laona
Cottage
Wango
Lamberton
Arkwright
Markham
POMFRET
DAYTON
VILLENOVA
Vineyard
Brocton
Shumla
ARKWRIGHT
Villenova
Portland
PORTLAND
Hamlet
Balcom
Griswold
South Dayton
Lillydale
Cassadaga
Burnhams
Dean
Stockton
CHERRY CREEK
CHARLOTTE
Charlotte Center
LEON
STOCKTON
Cherry Creek
Leon
CHAUTAUQUA
Moons
Hartfield
Jamestown Junction
Sinclairville
Thornton
Centralia
CONEWANGO
Mayville
Wooglin
GERRY
ELLINGTON
Tupper Cr.
Crooked Brook
Canadaway
Walnut
Mud Lake
East Mud Lake
North Branch
West Branch
Canadaway Creek
Bear Lake Outlet
Cassadaga
Creek
Mill Creek
Clear Creek
Conewango Creek
Mud Creek
East Branch
Slab City Cr.
Johnson Cr.
Middle Lake
Lower Lake
Bear Lake
Dewittville Creek
Big Inlet
Chautauqua Lake
Mill Cr.
LAKE SHORE AND MICHIGAN SOUTHERN R.R.
NEW YORK, CHICAGO AND ST. LOUIS R.R.
DUNKIRK, ALLEGHENY VALLEY AND PITTSBURG R.R.
BUFFALO AND SOUTHWESTERN R.R.
ERIE R.R.
W.N.Y. AND P.R.R. PITTSBURG DIV.
BELMORE BEACH
FOREST BEACH
DELTA
CHAUTAUQUA CO.
CATTARAUGUS CO.
STATE DRAINAGE DITCH
79°30′
79°00′
25′
20′
15′
10′
5′
42°15′
JULIUS BIEN & CO. LITH. N.Y.


PLEISTOCENE MAP
OF PART OF
DUNKIRK, CHERRY CREEK AND SILVER CREEK
QUADRANGLES, NEW YORK
BY FRANK LEVERETT
Scale
Contour interval 100 feet
Datum is mean sea level
1900
LEGEND
Morainic drift
Mainly plane-surfaced drift
Glacial drainage
Beaches
Lake Whittlesey
Lake Warren
Alluvial
Roads
LAKE ERIE
EVANS
BRANT
COLLINS
PERRYSBURG
SHERIDAN
DUNKIRK
POMFRET
PORTLAND
ARKWRIGHT
VILLENOVA
DAYTON
CHARLOTTE
CHERRY CREEK
LEON
STOCKTON
CHAUTAUQUA
GERRY
ELLINGTON
CONEWANGO
East Evans
Evans
Angola
Farnham
Brant
Fenton
Irving
Silver Creek
Hanover Center
Smiths Mills
Forestville
Dunkirk
Van Buren Pt.
Cordova
Fredonia
Laona
Lambertson
Arkwright
Brocton
Portland
Vineyard
Shumla
Griswold
Villenova
Balcom
Wango
Cottage
Markham
South Dayton
Lillydale
Cassadaga
Burnhams
Dean
Stockton
Charlotte Center
Cherry Creek
Moons
Sinclairville
Hartfield
Jamestown Junction
Wooglin
Centralia
Mayville

taraugus Creek is shown in Pl. XIX. In the valley-like depression at the north end of Lake Chautauqua two distinct moraines are found. An outer weak one extends from Little Chautauqua Creek southeastward to within 2 miles of the head of Lake Chautauqua, and there turns abruptly northward along the west side of Inlet Creek and joins the main belt east of Prospect. The main belt leads northeastward along the north side of Little Chautauqua Creek to its source, and there becoming united with the outer belt, continues through the south part of Portland Township to the valley-like depression in which Bear Lake stands, where it again separates from the outer belt. The outer belt, which here also is weak, leads eastward to Bear Lake, and then returns northward to join the inner or main belt on the high divide between Bear Lake Valley and Cassadaga Creek. The inner belt leads directly northeast across Bear Lake Valley, passing about a mile north of the lake. The united belt swings around the north end of the high divide between Bear Lake and Cassadaga Creek, and takes a southward course into the Cassadaga Valley at Upper Cassadaga Lake.

From Cassadaga Valley two moraines lead eastward. A weak outer one passes from Cassadaga Village northeastward to Arkwright, while a strong inner one leads from Upper Cassadaga Lake to the same point, a portion of its course being along the north side of the westward-flowing part of Canadaway Creek.

The combined belt leads eastward from Arkwright past Arkwright Summit to the valley or depression in which West Mud Lake lies, and includes that lake in its outer border. It then makes an abrupt northward turn along the face of the hills east of West Mud Lake, and crosses over to the valley-like depression in which East Mud Lake lies. In this depression there was less lobation of the ice margin than in similar valleys to the west, the course of the moraine being eastward across the valley and the uplands east of it to Slab Creek, a headwater tributary of the Conewango, and thence over another ridge south of Perrysburg to the broad valley of the Conewango, which afforded the old line of discharge for the Upper Allegheny.

In crossing this valley the moraine takes a northeastward course through Dayton to South Cattaraugus Creek, coming to that stream about midway between Gowanda and Cattaraugus. It is very ill defined east of this creek for 3 or 4 miles, but seems to follow the east bluff northward nearly to the

main Cattaraugus Creek. From that point a weak outer belt makes a detour southward in crossing the old valley of South Cattaraugus Creek and returns northward along the east side of the valley to the main Cattaraugus Creek.

A stronger belt sets in on the north side of Cattaraugus Creek opposite the old valley and thence leads northeastward along the divide between northern tributaries of Cattaraugus Creek and streams which flow directly toward Lake Erie. Indeed the moraine to a large degree constitutes the divide from this point up to the head of Cattaraugus Creek, in western Wyoming County.

At the head of Cattaraugus Creek there is a reentrant between the lobe that extended westward into the Lake Erie Basin and one that extended southward up the Genesee. Between these lobes an interlobate moraine was formed which occupies the high divide west of the Genesee and extends northward from Wethersfield and Java townships in southwestern Wyoming County to Bennington Township in the northwest corner of the county, a distance of about 15 miles.

From the east side of this interlobate moraine a strong moraine leads southeastward to the Genesee River, having a width of 6 or 8 miles in Wethersfield, Gainesville, Pike, Castile, and Genesee Falls townships, Wyoming County, and coming to the river in the vicinity of Portage Falls. The writer has not traced its course beyond the Genesee, but it is supposed to be continued around the southern ends of the Finger lakes of western New York.

For a short distance outside the ridged and hummocky part of this morainic system in eastern Erie County, Pa., and in Chautauqua County, N. Y., there are often large numbers of bowlders, which it is thought may have been deposited by the ice sheet at about the time the moraine was forming, the moraine being a submarginal and the bowlders a strictly marginal deposit. The bowlders are very conspicuous just outside some of the reentrants in the moraine, suggesting that the ice border may have passed more directly over the ridges which stand in these reentrants than the border of the morainic ridges would indicate, and also have reached an altitude somewhat higher. The bowlders are, however, conspicuous only for a mile or so beyond the morainic ridges, and to altitudes 100 to 150 feet above them.

RANGE IN ALTITUDE.

The outer or south border of this morainic system is, throughout much of its course, much higher than the inner border, because of its situation on the face of an escarpment. The difference is only about 100 feet in the Ohio portion, but in Erie County, Pa., it reaches 400 feet, and in Chautauqua County, N. Y., fully 600 feet.

In Ohio the altitude of the entire system shows scarcely 200 feet variation, the lowest parts being about 775 feet above tide, and the highest scarcely 950 feet. Indeed, it lies mainly between the 800- and 900-foot contours.

There is but little rise shown in crossing the Girard, Pa., quadrangle, but in the southwest part of the Erie quadrangle, north of Sterrettania, an altitude of 1,000 feet is reached, and 1,000 to 1,100 feet is maintained along the crest of the morainic belt in the central and eastern parts of the quadrangle. Between the Erie quadrangle and the New York line the crest of the moraine rises to about 1,200 feet, and near the Westfield geodetic station reaches an altitude of 1,480 feet

In the valley-like depression at the head of Lake Chautauqua the outer border of the moraine stands between 1,340 and 1,400 feet. On the divide between Chautauqua and Bear lakes it rises slightly above the 1,500-foot contour, but drops in the Bear Lake depression to 1,325 feet. Northeast of Bear Lake it again rises to about 1,500 feet, and then drops to about 1,310 feet in the Cassadaga Valley. Near Arkwright it makes a still greater rise, and appears on a hill north of the village that rises to the 1,740-foot contour. In the valley east of Arkwright, near West Mud Lake, the altitude falls to about 1,400 feet, some knolls being found between the 1,380- and 1,400-foot contours. On the uplands between East and West Mud lakes an altitude of 1,680 feet is reached. Around East Mud Lake morainic knolls appear down to the 1,340-foot contour, but the crest north of the lake is about 1,400 feet in its lowest part. Between East Mud Creek and Slab Creek Valley the moraine rises to the 1,560-foot contour, but drops 200 feet in Slab Creek Valley, its crest being just above the 1,360-foot contour. On the uplands between Slab Creek and the Conewango Valley it rises to about the 1,600-foot contour. In Conewango Valley the crest is not far from the 1,400-foot contour, but the outer face extends down to about 1,340 feet. It rises east of South Cattaraugus Creek to about 1,650 feet,

but drops to less than 1,400 feet on the borders of the main Cattaraugus Valley.

In the portion which follows the divide north of Cattaraugus Creek the altitude ranges between 1,400 and 1,800 feet in crossing the sags and ridges, there being a variation similar to that in the portion between Lake Chautauqua and the Conewango Valley. As this district has not been covered by the topographic survey, only general statements can be made. Near the head of Cattaraugus Creek, in the interlobate belt, a still greater altitude is attained, some points being nearly 2,000 feet.

Between the interlobate belt and the Genesee the moraine descends several hundred feet, the altitude in the vicinity of Portage Falls being between 1,150 and 1,350 feet. The original level of the crest of the moraine in the Genesee seems to have been fully 1,300 feet.

From the data just given it seems probable that the ice sheet had greater thickness in the eastern portion of the Lake Erie Basin at the time it was forming this morainic system than in the central or western portions. This seems due to its having had at that time an axial movement westward into the Lake Erie Basin. The eastern portion, being nearer the center of dispersion, would naturally carry a thicker sheet of ice than the more remote western portion.

It may not be possible to compute the thickness definitely, but a rude approximation may perhaps be reached by considering the altitude and position of the moraine. The moraine-covered hill near Arkwright, 1,740 feet above tide, is but 3 miles distant from the base of the steep escarpment, which stands 900 feet lower, or only 840 feet, but 7 miles distant from the shore of Lake Erie at Dunkirk, where the altitude of the lake bed is less than 570 feet, and 24 miles distant from the axis or deepest part of the Lake Erie Basin, where the altitude is only 380 feet. Were the ice sheet no higher in the midst of the lake basin than this moraine-covered hill, its thickness opposite Arkwright and Dunkirk would have been nearly 1,400 feet. But it is probable that the ice margin rose considerably above this moraine-covered hill, and that there was a gradual ascent from the margin northward to the midst of the lake basin. The thickness of the ice sheet, probably reached fully 2,000 feet in the midst of the lake basin north of Dunkirk. If the ice sheet had had a similar thickness opposite the north end of the Grand River Basin, there should have been a decided

protrusion into the basin. But instead this morainic system passes the basin with scarcely a mile of southward deflection. It is strikingly in contrast with the Cleveland, or next earlier morainic belt, which has a loop extending southward 20 to 25 miles into the basin.

It may be objected that the movement toward the border of the basin was comparatively weak, the main movement being along the axis. This objection is, however, only another way of stating that the ice sheet was too thin in this part of the lake basin to have a strong movement. It is doubtful if its thickness was half that of the portion in the eastern end of the basin.

RELIEF.

Along its outer border this morainic system usually shows a relief of 20 to 40 and occasionally 60 feet; but the country to the south rises rapidly and soon reaches an altitude much above the morainic crest. The relief is best shown where the moraine crosses valleys, such as the Cassadaga, Chautauqua, and Conewango, but it is in many places conspicuous along the face of the escarpment.

Between the members of this morainic system there are valley-like sags, above which the ridges rise to heights of 20 to 40 feet or more, there being nearly as much relief as on the outer border of the system. The sags afford convenient lines for streams to follow, and the peculiar winding courses and sharp deflections of the creeks on the south border of the Lake Erie Basin in northwestern Pennsylvania and northeastern Ohio are in large part due to the controlling influence of the sags.

TOPOGRAPHY.

This morainic system, like the earlier ones, presents considerable variation in topographic expression, ranging from a comparatively smooth ridge with only gentle undulations to intricate hummocky tracts inclosing basins that hold ponds and small lakes. Between these types is the well-defined ridge that carries sharp hummocks and has its surface indented with basins. There is also some contrast between different moraines of this system, the Euclid moraine having, on the whole, less strength of expression than the other moraines. In the detailed discussion which follows, the Euclid is first considered, after which the other moraines follow in turn from the outer toward the inner part of the morainic system.

From Euclid eastward into Lake County there are only a few low swells and a very faint ridge to mark the position of the moraine, the largest swells being scarcely 10 feet in height. Near the southwest corner of Lake County a more distinct ridge appears, which presents a relief of 10 to 25 feet, and has swells 5 to 15 feet in height along its crest and on its slopes. There are also a few knolls scattered over the plain on the south border of the ridge. These features continue through to Chagrin River, a distance of 3 or 4 miles. East of Chagrin River, along the north side of East Chagrin River, there is a ridge 10 to 20 feet in height with a breadth of a mile or less. Its surface is very gently undulating, with swells but 5 to 10 feet in height. An old channel follows the south border of this ridge from the bend of Grand River south of Painesville westward to East Chagrin River, which seems to have been the line of discharge for glacial waters into Lake Maumee. In this channel, about 3 miles southwest of Painesville, there is an outlying ridge that trends northeast to southwest in harmony with the main ridge and rises nearly 50 feet above the level of the channel in which it stands.

The portion of the Euclid moraine which lies along the south side of Grand River presents a series of loosely connected knolls and short ridges, 10 to 20 feet in height, covering a belt only one-half mile to a mile in width. There does not seem to be a definite basement ridge, such as appears in portions of the moraine to the east and west.

From the Grand River Valley eastward into Pennsylvania the Euclid moraine consists of a faintly outlined ridge with a relief of but 10 to 20 feet, yet this is sufficient to hold Griggs Creek in a westward course along its outer border from source to mouth and to cause Mill Creek to turn westward into Grand River. In eastern Ashtabula County, Ohio, it causes a tributary of Ashtabula Creek to flow westward on its outer border, while in western Erie County, Pa., it causes a tributary of Conneaut Creek to turn abruptly eastward. As above noted, this moraine has not been recognized farther east than the northward-flowing part of Conneaut Creek, in Erie County, Pa.

Returning to Painesville and taking up the description of the Painesville moraine, we find a somewhat sharp ridge, 20 to 40 feet in height, and from a half mile or less to fully a mile in width. Its crest as well as slopes carries swells and sags, with oscillations of 10 to 25 feet or more.

Throughout its course, from Painesville eastward into Pennsylvania, it displays much greater strength than the Euclid moraine. Its influence upon drainage is a notable feature, and one showing its almost perfect continuity. Grand River is made to take a westward course for about 20 miles along its outer border from the bend near Austinburg to the bend at Painesville, thus greatly increasing its distance to Lake Erie. The headwater part of Ashtabula Creek, from its source westward to Kelloggsville, Ohio, also has its course determined by this morainic ridge, and is prevented from flowing directly north to Lake Erie.

After combining with the Euclid moraine in western Erie County, Pa., there is but little change in the topography from that presented by the Painesville moraine west of the point of union. There is usually a well-defined crest and a sharply undulating surface, on which the knolls are 10 to 25 feet or more in height. The part of the moraine between Conneaut Creek and Elk Creek, as may be seen by reference to Pl. XVIII, holds small drainage lines between it and the base of the rock escarpment to the south, one line leading northeastward into Little Elk Creek, and the other southwestward into Temple Creek, a tributary of Conneaut Creek. Between these is another stream which finds a gap in the moraine through which it passes northward into Elk Creek. Little Elk Creek takes advantage of a similar gap near its mouth; but an eastern tributary of Little Elk Creek is turned westward between this moraine and the base of the escarpment. Elk Creek owes its southwestward deflection of 3 or 4 miles, near Sterrettania, to the presence of this moraine on its north side.

The Ashtabula moraine differs but little in strength and in topographic expression from the Painesville moraine. Its width is one-half mile to a mile or more, and its crest stands 30 to 60 feet or more above the bordering sag on the south and the plain on the north. The outer or south face is much more abrupt than the inner. It is sharply undulating, and where strongest it has knolls 20 to 40 feet in height. The weakest part is immediately west of Kingsville, where for a couple of miles it rises but little above the old lake bottom, and has perhaps been worn down to some extent by the waves. The portion along the north side of Conneaut Creek from Kingsville, Ohio, eastward to Lexington, Pa., is exceptionally strong, its height being 40 to 60 feet above the creek bluff. Immediately east of Lexington it is interrupted by a narrow gap through which Crooked Creek

finds a passage, while at Kingsville it affords a wider gap for Conneaut Creek to turn north toward the lake.

From Conneaut Creek to Elk Creek the moraine, though having a well-defined crest, carries gentler swells than in the neighboring portions to the west and the east. From Elk Creek eastward to its junction with the Painesville moraine it presents a series of sharp knolls distributed over the slopes and along the crest of a prominent basement ridge. Parts of the ridge stand 60 to 80 feet above the sag on the south, which is drained by Brandy Run.

Along the south side of Walnut Creek from near Sterrettania up to Kearsarge there is an intricate assemblage of knolls and sags without so well defined a basement ridge as appears to the west, where the moraines are more distinct. The largest knolls are 30 to 40 feet in height and are rather sharp. A similar confused assemblage of knolls continues across the interval between Walnut Creek and Mill Creek to the point of connection with the Girard moraine at the bend of Mill Creek south of Erie. Walnut Creek owes its deflection from the base of the escarpment westward to Kearsarge to the presence of this morainic system between Kearsarge and Mill Creek. Otherwise the headwater portion would have continued northward to Mill Creek and thence through the midst of the city of Erie into the lake, as may be seen by reference to Plate XVIII.

In the range of sharp knolls which leads from Cross Station toward Girard the highest points rise about 70 feet above the Maumee beach on the north slope, but are seldom as much as 30 feet higher than the gravel plain on the south or outer face. In places the knolls barely reach the level of the gravel plain.

In the western part of the Girard moraine there is a gently undulating ridge with swells only 10 to 12 feet high, and a relief of 15 to 20 feet above the plain on its outer or south border. This weak phase continues to Walnut Creek Valley at Swanville; but from Walnut Creek eastward to Mill Creek, a distance of 9 miles, this moraine is about as strong as and is similar in topography to the best developed parts of the Painesville and Ashtabula moraines. It is fully a mile in average width and consists of a well-defined basement ridge on whose crest and slopes knolls 10 to 40 feet in height appear. The variations in the strength of the Girard moraine are clearly brought out in Pl. XVIII.

From the bend of Mill Creek south of Erie, Pa., eastward nearly to the north end of Lake Chautauqua, N. Y., this morainic system, as above noted, is combined into a single strong belt. Along its south border there is often a somewhat sharp ridge forming the crest line of the belt and standing 20 to 30 feet or more above the immediate border. Where the moraine crosses Sixmile Creek there is a small tract of level land lying between it and the escarpment to the south. A similar low plain at Sixteenmile Creek is traversed by the creek for a mile or more near Grahamsville. In western Chautauqua County, N. Y., there is a similar narrow plain several miles in length which has been utilized by Twentymile Creek in its westward course.

From this ridge northward down the face of the escarpment the drift knolls are distributed singly or in groups. They are often so closely aggregated as to give the face of the escarpment a hummocky appearance, but in places are scattering. The lower part of the escarpment generally has fewer knolls than the upper part.

From the New York line eastward to the Westfield geodetic station numerous shallow basins were found among low swells along or near the crest of the moraine. Such basins are less numerous, though not rare, in Erie County, Pa.

The outer moraine in the depression at the head of Lake Chautauqua is a gently undulating till ridge, with swells scarcely 10 feet in height, among which there are numerous saucer-like depressions. At the south border it stands only 8 or 10 feet above a gravel plain that leads down to Lake Chautauqua, being near the 1,340-foot contour, but the crest in places reaches the 1,400-foot contour. It is not certain, however, that this relief of 60 feet is entirely due to drift accumulations; possibly the crest follows in part a rock ridge.

The topography of the outer moraine in the Bear Lake Valley is somewhat different from that in the Chautauqua, there being only scattering knolls without a well-defined basement ridge. The outer of the two moraines which lead from the Cassadaga Valley toward Arkwright consists of a gently undulating till ridge which, for a couple of miles northeast from Cassadaga village, forms a divide between a southward-flowing and a westward-flowing tributary of Cassadaga Creek, as indicated in Pl. XIX.

The inner or main moraine from the head of Lake Chautauqua eastward

presents topography similar to that toward the west, there being in places a narrow ridge scarcely an eighth mile in width and 30 to 40 feet or more in height forming the crest, while numerous hummocks and basins appear on its inner border for about a mile north from the crest. Such a sharp-crested ridge is a conspicuous feature for 2 or 3 miles in the part of the moraine immediately west and north of Bear Lake, as may be seen by reference to the Dunkirk topographic sheet (see Pl. XIX). Just outside this sharp moraine is a smooth gravel plain.

On the slopes north and northwest from the upper Cassadaga Lake there are a few drift knolls 20 to 40 feet or more in height, among which are numerous small ones only 5 to 10 feet high. In Cassadaga Valley a gravelly tract occurs around the upper and lower lake, which carries a few low knolls and presents apparently a gradation from the moraine into a plain that sets in south of the lower lake.

On the high ridge near Arkwright the moraine has a hummocky surface, with numerous knolls 10 to 15 feet and a few 20 or 25 feet in height. This topography extends down the slope eastward to West Mud Lake.

The valley below West Mud Lake carries a smooth gravel plain, but near the lake it becomes full of basins, the largest of which is occupied by the lake. They extend up to the moraine which forms the divide north of the lake, and which presents a sharply ridged surface. North from the morainic crest sharp knolls occur for a mile or more. Many of the knolls are small, being only 10 to 15 feet in height and covering only an acre or two. There are basins among them that occupy only a few square rods, yet are several feet in depth.

The hummocky topography leads eastward over the ridge to East Mud Lake, where the moraine presents features similar to those around West Mud Lake, there being a gradation from the gravel plain south of the lake through basins in and around it to the sharp-crested moraine that passes it on the north. The basins on the border of the lake are 8 to 10 feet deep and only a few acres in extent, but the lake itself occupies a basin nearly an eighth of a mile across.

From East Mud Lake eastward to Perrysburg knolls 20 to 30 feet high are quite numerous and are arranged in chains with trend in line with the moraine, or nearly east to west. The tendency to an east-to-west ridging becomes still more conspicuous in the area extending from Perrysburg

southeastward into the Conewango Valley. The ridges are in some cases 30 to 40 feet high and a half mile or more in length. There are also numerous conical knolls 10 to 20 feet high, among which are shallow basins. At the south border of the moraine there is a gradual transition to a gravel plain that leads down to the Conewango Swamp, near South Dayton. A similar transition is found in Slab Creek Valley west of Perrysburg.

This strong moraine, as above noted, dies out at the west bluff of South Cattaraugus Creek, about 5 miles south of Gowanda, there being only scattering drift knolls on the east side of that valley. But upon crossing over the ridge to the old valley, about 3 miles northeast, the moraine again appears, though its ridges and swells are of a more subdued type than in districts to the west. The swells are only 10 to 15 feet high and have very gentle slopes, while the crest is a barely perceptible ridge.

On the north side of Cattaraugus Creek between the creek and Collins Center there is a topography similar to that in the Conewango Valley near Dayton. The ridges and knolls are 20 to 30 feet high and among them are sloughs and saucer-like depressions. There is but little change in topography in passing northeastward over the high ridge north of Mortons Corners to Woodward Hollow (Wyandale post-office), though the knolls are sharper on the elevated tract than on the lower ground. Knolls 20 or 25 feet high may be seen distinctly for a distance of 2 miles, their slopes are so abrupt. Among the knolls are basins with abrupt rims instead of the saucer-like depressions noted near Collins Center.

In the valley both north and south of Woodward Hollow there are sharp knolls, 10 to 25 feet or more in height, among which basins are inclosed, but the tendency to ridging is not so pronounced as to the west. The east slope of the valley also presents a hummocky surface through the entire width of the belt, which is here nearly 3 miles.

Farther east, on the meridian of Springville and eastward past East Concord, the moraine grades on the south into a gravel plain which leads westward some distance down Cattaraugus Creek. Low gravelly swells appear at the junction of the plain with the moraine. There is considerable gravel outwash along the moraine from Springville up to the head of Cattaraugus Creek, setting in near the level of the crest of the moraine and sloping southward. North of the crest the moraine is in places lower than the gravel plain and yet carries sharp knolls and basins. The knolls extend

north along the valleys some distance farther than on the intervening ridges, giving the appearance of spurs. They are perhaps the lines of subglacial drainage, many of the knolls being gravelly and a few having the form of eskers.

The interlobate portion of this morainic system in western Wyoming County presents in its southern part a very sharp knob-and-basin topography, scarcely an acre of the surface being plane. The knolls rise usually but 20 to 30 feet above the basins, and there are many very small, sharp hummocks only 5 to 10 feet in height. Upon passing northward in the interlobate belt the knolls become more scattering and among them are areas of considerable extent which have a nearly plane surface. The knolls are, however, in some cases rather large, some of them being 40 to 50 feet in height.

The portion of this morainic system between the interlobate tract and the Genesee River also presents a sharp knob-and-basin topography, with knolls 10 to 30 feet or more in height inclosing numerous small basins. There is some tendency to aggregation in belts that trend northwest to southeast in line with the trend of the system, but this tendency is scarcely so marked as in the district west of the interlobate tract. There are also strips a mile or so in width in the midst of this system in which knolls are rather rare. These suggest intermorainic tracts, but they are not continued far enough to cause a separation of the system into distinct moraines.

STRUCTURE OF THE DRIFT.

In the gently undulating morainic ridges from Euclid, Ohio, eastward into Pennsylvania there is a clayey till similar to that found in the plains farther west, and but few gravel knolls occur. The coarse material becomes more conspicuous as the moraine rises along the escarpment in Erie County, Pa., and Chautauqua County, N. Y., while on some of the high ridges farther east the stones are so abundant as to give the moraine a gravelly appearance. The outer belt in the valley-like depressions at the head of Lake Chautauqua and at Cassadaga and Bear lakes carries a more clayey till than the inner or main belt. There is also a very clayey till in the old Upper Allegheny or Conewango Valley and the old course of South Cattaraugus Creek. But from the crossing of Cattaraugus Creek near Collins Center eastward to the interlobate moraine the till is very stony and gravel

knolls abound. Gravel knolls are more conspicuous in the valley-like depressions than on the ridges, both in the district north from Cattaraugus Creek and that west from it in Chautauqua County, N. Y.

The interlobate moraine carries a large number of gravel knolls, and the till knolls contain a large amount of coarse material. The depressions among the knolls have, on the whole, a coarser drift than is usually found in the portion west of the interlobate, where a compact till predominates.

The portion of this morainic system between the interlobe and the Genesee River has about the same structure as the interlobe, there being a large number of gravel knolls and a rather stony drift in the till knolls.

Surface bowlders are common all along the morainic system, but are especially abundant in the New York portion. They are largely granitic rocks, though in many places Canadian crystallines are represented.

Parts of this morainic system have been classed with the beaches by early writers.[1] This confusion appears to have arisen mainly from the imperfect knowledge of the phases of structure which a moraine may present, especially the stony phase, though in one of the instances above cited a ridge of clayey till is called a beach. In Read's "Profile section from Lake Erie to Grand River,"[2] the southernmost of the four ridges there shown is the Painesville moraine and is described as a ridge of bowlder clay. The beaches are narrow ridges only a few rods wide, while the moraine has a width of one-half mile or more. The beaches are composed of assorted material, the moraine of till, with occasional developments of gravelly knolls In places in Ashtabula County the moraine and beach are so closely associated that beach sand appears on the moraine, but through much of its course in Ashtabula County, as well as elsewhere, the moraine is free from beach deposits and from evidences of wave action. The following description by Read, taken from the report on Ashtabula County,[3] will make it evident that a glacial ridge rather than beach is described:

> The old "lake ridges" and terraces are well defined in the county, and railroad excavations have afforded unusual facilities for studying their character. The outer or southern ridge, where exposed by railroad cuts, is shown to be a ridge or wall of compact unstratified clay, composed largely of the local rocks, but with many frag-

[1] I. C. White: Second Geol. Survey Pennsylvania, Rept. Q^4, pp. 38, 39. M. C. Read: Geology of Ohio, Vol. I, 1873, pp. 488–490, 516–518; Vol. II, 1875, pp. 60–63.

[2] Geology of Ohio, Vol. I, p. 518.

[3] Geology of Ohio, Vol. I, p. 488.

ments of granite and other metamorphic rocks, not rounded by the action of waves but in irregular forms, ground, polished, and marked with striæ and scratches on all sides.

On page 489 the following section is presented by Read, and with it a few remarks on the drift clays of the Painesville moraine, exposed on the bluff of Ashtabula Creek:

Section of the Painesville moraine at the bluff of Ashtabula Creek.

	Feet.
1. Sandy loam	1–2
2. Yellow clay, with fragments of shale	10
3. Blue clay, with fragments of shale and bowlders	14
4. Fine sand, local	0–3
5. Coarse gravel, coarsest at bottom	10
6. Blue clay, with bowlders	50
7. Erie shale in place.	

The yellow and blue clays are wholly unstratified, composed of the débris of the Erie shales, with numerous fragments of granite rocks. The coarse gravel in the middle of the section is of similar fragments, with the clay washed out of it. The mass bears no resemblance to the shingle of a water-washed beach, the gravel not being polished and rounded into pebbles, but apparently the result of a mass of mud pushed up into a position where drainage has carried off the softer and more liquid materials. The local bed of sand (4 above) is stratified, indicating a temporary local space of open water apparently soon closed up, and the ice pushing the unstratified clay above it. This ridge with its mass unstratified and without rounded, water-worn pebbles, can not be the slow accumulations of a water-washed beach, nor can the materials have been deposited in any way which permitted them to fall through water which would sort and stratify them.

In Read's descriptions of the "south ridge" in Lake County, the upper beach line and the moraine are not clearly distinguished. The "south ridge" in Willoughby Township is the Euclid moraine, and in the eastern part of Lake County is the Painesville moraine, but what is termed the south ridge at Painesville is the Belmore beach. It is remarked concerning the moraine in Willoughby Township that "the southern lake ridge here, and in a large part of the county, is mostly composed of unstratified clays, but is irregular and not well defined."

Concerning the Belmore beach at Painesville, the following remarks and section are presented:[1]

At Painesville the south ridge is in places largely composed of coarse, stratified gravel, but it has been modified by subsequent action. The following is a section from

[1] Geology of Ohio, Vol. I, 1873, pp. 516–517.

a cut made by the Painesville and Youngstown Railroad on the north bank of the river:

Section of Belmore beach south of Painesville.

	Feet.
Coarse gravel, without distinct bedding	12
Fine stratified gravel	4
Coarse gravel obliquely stratified, changing below to fine gravel with irregular waved lines of stratification	6–12

In the above section the upper 16 feet constitutes the beach proper. The lower part of the section is an earlier formation of glacial age. The gravel is cemented with lime and contains much calcareous sand and rock flour produced by glacial grinding. The obliquely stratified gravel lies below the level of the base of the inner slope of the beach, and is probably no more closely related to the beach gravels above it than is the till which so often underlies beach gravels, the beach gravels in both cases being produced at a later period by the waves of the lake, while the underlying gravels or the till were produced by glacial agencies.

The following description of the moraine east of Painesville is given by Read:[1]

> The bluff of the river is 250 feet above the lake. An irregular clay ridge, half a mile north of the bluff and about 5 miles from the lake, is here the most southern well-defined lake beach. It is 260 feet above the lake, and composed of bowlder clay, with a surface somewhat irregular from the effects of erosion, but gently sloping to the sandy ridge on which Madison village stands, the surface generally becoming sandy as this ridge is approached.

Thus it appears from the descriptions that the "south ridge" when a moraine is composed of bowlder clay, and when a beach, of sand and gravel. It is, however, but fair to call attention to the fact that Read appears to have held at one time the view that the till ridge is a moraine, even though in his description he calls it a lake ridge. Newberry states[2] that Read had regarded this ridge as a moraine, but that he (Newberry) considered it a clay terrace which had been cut by the lake. The chief geologist of the Ohio survey thus appears to have been influential in turning his subordinate from a correct to an erroneous interpretation.

OUTER BORDER DRAINAGE.

The lines of escape of glacial waters on the outer border of this morainic system are very plainly indicated along much of the border.

[1] Geology of Ohio, Vol. I, 1873, p. 518. [2] Ibid., Vol. II, 1875, pp. 60–61.

From the Conneaut Valley, in western Pennsylvania, westward to the terminus of the moranic system near Euclid, Ohio, there are well-defined channels between it and the rock escarpment, one of which is outside the Euclid moraine and others between the moraines. These channels are still utilized in large part by small westward-flowing streams which after following the line of glacial discharge for a few miles now turn northward through gaps in the moraines. Between these streams there are short sections of the glacial channel not utilized by the present drainage. Perhaps the most conspicuous abandoned part leads from the bend of the Grand River south of Painesville westward to East Chagrin River near Kirtland, and this has a length of but 5 or 6 miles. The interval between Ashtabula Creek, south of Kellogsville, and the head of Griggs Creek is scarcely 2 miles, and there is a similar interval between Chagrin River and Euclid Creek. In each of these places there is a well-defined abandoned channel.

From western Chautauqua County, N. Y., westward to Conneaut Creek Valley the waters no doubt found passages along the face of the escarpment either outside or just within the edge of the ice sheet, but sufficient attention has not been given to the channels to determine their full courses and connections.

From the Chautauqua Valley eastward to the Conewango there are, as already indicated, moraine-headed terraces in each of the valleys discharging southward that contain a gravel outwash from the ice sheet and were evidently lines of vigorous discharge. Some of these terraces have their heads at the brow of the escarpment overlooking Lake Erie (see Pl. XIX), and yet lead directly away from the lake to the Allegheny River and thence through the Ohio and Mississippi to the Gulf of Mexico.

In the headwater portion of Cattaraugus Creek there appears to have been a vigorous movement of the waters along the front of the ice sheet, such as would call for adequate outlet to the west. Fairchild has recently determined that there was a discharge from the South Cattaraugus past Persia Siding to the Conewango at an altitude but little above 1,300 feet above tide. Fairchild has also found evidence that the discharge shifted from this channel to channels leading westward from Gowanda along the face of the escarpment as the ice melted back. His studies are still in progress (in 1900) and promise to bring out an interesting drainage history.

The drainage from the part of the morainic system in the vicinity of

the Genesee River seems to have been southeastward to the Canisteo River, a tributary of the Susquehanna, through the Burns-Arkport channel, brought to notice by Fairchild.[1] An outline of this line of discharge, given by Fairchild, is as follows.[2]

> When the ice uncovered the region of Portageville the Genesee waters found an avenue of escape, 150 feet lower than Cuba, over the morainic dam east of Portageville and filled the Upper Nunda (Kishawa) Valley to the height of the col north of Swains. Overflowing by the Swains-Canaseraga channel into the Dansville Lake, the water ultimately escaped by the Poags Hole col, past the sites of Burns and Hornellsville, to the Susquehanna.

INNER BORDER PHENOMENA.

From the western terminus, near Euclid, Ohio, eastward to the vicinity of Dunkirk, N. Y., there is a narrow plain lying between this morainic system and Lake Erie. It slopes rapidly from the base of the escarpment, or from the inner border of the morainic system, toward the lake. The greater part of it has been under lake water and well-defined beaches, descriptions of which appear in Chapters XV and XVI, mark the different levels which the lake water has held.

Over much of this lake plain rock is within a few feet of the surface, but there are filled valleys crossing the plain in which the drift is very thick. Their courses are in some cases entirely concealed, and generally are rendered quite obscure by the drift filling. The bluff of the lake often shows places where valleys come in whose courses across the lake plain are entirely concealed.

The lake and stream bluffs and the well borings show the drift to be largely till. The coarse pebbles are scarcely so numerous as in the moraine and in places are rare, but, as a rule, this till differs little from the clayey till which covers the plains to the west of Lake Erie. In the intervals between the beaches there is a surprisingly small amount of sand or other wave-washed material, till being usually found within a few inches or at most but a few feet of the surface. The material covering the rock is therefore largely glacial.

Upon passing eastward from Dunkirk the Gowanda moraine soon appears and lies within a few miles north of this morainic system from that

[1] Glacial lakes of western New York, by H. L. Fairchild: Bull. Geol. Soc. America, Vol. VI, 1895, pp. 358–359. Also Glacial Genesee lakes: ibid, Vol. VII, 1896, pp. 438–440, pls. 19 and 20.

[2] Ibid., p. 439.

place eastward to the interlobate moraine in western Wyoming County. The portion of the Gowanda moraine west of Cattaraugus Creek lies along the south border of the lake plain near the base of the escarpment, and is separated from the morainic system under discussion only by a narrow strip, in places a mile or less in width, along the face of the escarpment; but from the point where it crosses Cattaraugus Creek, at Gowanda, northeastward to the interlobate moraine, the Gowanda moraine lies a few miles north of the inner border of this morainic system. This strip between the moraines, although involving the same succession of ridges and valleys that are crossed by the moraines, is strikingly different from the morainic strips. The slopes and crests of the ridges are nearly free from drift swells and the valley bottoms are smooth and open. The drift is also perceptibly thinner on the ridges than in the morainic strips.

East from the interlobate moraine there is, for some distance north from this morainic system, a somewhat hilly region with comparatively few drift knolls and a much thinner deposit of drift than appears in the moraine. The knolls do not seem to be arranged in such definite belts as in the Gowanda and Hamburg moraines which connect with the western side of the interlobe, yet their deposition probably extends over the time occupied in the production of each of these moraines.

RELATION TO LAKE MAUMEE.

The Lake Escarpment morainic system was apparently formed during the lower stage of Lake Maumee while it stood at the level of the Leipsic beach. That beach, as indicated on pp. 734–738, can be traced with some certainty as far east as the vicinity of Girard, Pa., though it is a comparatively weak beach from Cleveland, Ohio, eastward. Farther east than Girard there are only faint and rather uncertain indications of wave action at the Leipsic level. The ice sheet appears to have persisted there until the lake had found a lower outlet and begun to form the Belmore beach.

SECTION V. MORAINES OF WESTERN NEW YORK SOUTH OF LAKE ONTARIO.

There are several short moraines in western New York between the Lake Escarpment system and the shore of Lake Ontario, two of which, the Gowanda and Hamburg, connect at the east with the interlobate moraine which extends northward from the Lake Escarpment system to northwestern

Wyoming County, while the remainder continue eastward past the north end of this interlobate moraine, in part as distinct ridges and in part coalesced. While they may have been formed in nearly as close succession as the several moraines of the Lake Escarpment system, they are on the whole more distinct from each other than those moraines, and should not perhaps be grouped as a single system. In the present discussion each morainic ridge receives a name, and the several ridges are considered in turn, beginning with the southernmost.

GOWANDA MORAINE.

DISTRIBUTION.

The westernmost appearance of the Gowanda moraine, so far as recognized, is in a chain of knolls which lies along the base of the escarpment in Sheridan Township, Chautauqua County, N. Y., from near Sheridan eastward to Walnut Creek at Forestville. On the east side of Walnut Creek it widens out to a strip a mile or more in width, which occupies the entire space between the Belmore beach and the base of the escarpment from Hanover Center eastward to the valley of Cattaraugus Creek at Gowanda. An isolated morainic tract, covering about 2 square miles, appears on the north side of Cattaraugus Creek, 3 to 5 miles east of Irving, as indicated in Pl. XIX. It stands below the level of the Forest beach, yet it presents a sharp knob-and-basin topography. Its relation to the Gowanda moraine is not understood.

After crossing Cattaraugus Creek near Gowanda the moraine turns northward, following nearly the base of the escarpment past Lawton at an altitude but little above the level of the Belmore beach. Northeast of Lawton it crosses over the ridge that lies between Cattaraugus and Eighteenmile creeks, passing 2 or 3 miles east of North Collins and coming to Eighteenmile Creek Valley at Clarksburg. Thence its course is northeastward over another ridge to the east branch of Eighteenmile Creek at Boston Center. It continues northeastward over a prominent ridge between East Eighteenmile and West Cazenovia creeks, and comes to the valley of the latter creek at West Falls. Thence its course is more nearly east across a ridge in southern Aurora Township, Erie County, to East Cazenovia Creek, at and north of the village of South Wales. It is not so well defined

farther east, but seems to continue across Wales Township, Erie County, to the interlobate moraine in Sheldon Township, Wyoming County.

The general width of this moraine is only about a mile and it is often considerably narrower. Its narrowest portions are usually the best defined, for the moraine is so weak that when spread over a width of more than a mile it becomes difficult to map its limits.

RANGE IN ALTITUDE.

The portion of the Gowanda moraine west of Cattaraugus Creek has a range of only about 100 feet in altitude, the lowest points being near the level of the Belmore beach, 840 to 850 feet above tide, and the highest about 950 feet. From Cattaraugus Creek northward past Lawton it remains at similar low altitudes, but in crossing the ridge east of North Collins it rises to about 1,300 feet. In each of the branches of Eighteenmile Creek its altitude is not far from 1,000 feet, but on the ridge between it is fully 1,300 feet. Farther east it fluctuates between about 1,100 feet in the valleys and 1,500 feet or more on the ridges, and is fully 1,500 feet at its junction with the interlobate tract in Sheldon Township, Wyoming County.

TOPOGRAPHY.

This moraine throughout its course consists largely of small swells, 10 to 15 feet high, which are separated by sags and winding, poorly drained depressions. Occasionally knolls 25 to 40 feet or more in height are found, and on the whole the portions in valleys carry larger knolls than the portions on ridges. Where the moraine is narrowed to about a half-mile the knolls are usually very closely aggregated and the expression is strong; but where it spreads out to a width of more than a mile the knolls become more scattering and the expression correspondingly weak. In the portion from South Wales eastward, as noted above, the knolls are very scattered and it becomes difficult in places to determine the limits of the moraine.

STRUCTURE OF THE DRIFT.

In the portion of the moraine west of Cattaraugus Creek, and also on the ridges farther east, the Gowanda moraine consists mainly of till. Wells often pass from a yellow into a blue till at 8 or 10 feet. The till is clayey in the low tract west from Cattaraugus Creek, but on the high tracts

it contains less clay and is thickly set with small fragments of the shaly sandstone of that region.

In the valleys of Eighteenmile and Cazenovia creeks there are heavy deposits of silt and fine sand which were apparently laid down in water. These are capped by a few feet of stony material, some of which is assorted. The knolls and ridges which constitute the moraine proper carry considerable gravelly material.

In railway cuttings north of Gowanda beds of gravel are exposed beneath the till, the till being in places only 6 to 8 feet thick. The gravel shows discordant stratification, some beds being horizontal and others having a sharp inclination. The gravel is only a local phase, for it passes horizontally into unmodified till within a space of a few rods.

A bank of till 100 feet in height is exposed on the west side of Cattaraugus Creek about a mile west of Gowanda. It is of blue color and clayey, yet much of it is thickly set with stones, there being only a small part in which pebbleless clay appears. The coarse fragments are largely of local shaly sandstone, but limestone pebbles are not rare, and there are not a few Canadian crystallines. This till was probably deposited while the ice sheet stood farther south than the Gowanda moraine, and may, therefore, not form a part of that moraine. It is capped by a few feet of gravel which was deposited as a delta in connection with the Belmore beach, its altitude being about the same as that of the beach.

The Gowanda moraine carries a remarkably large number of surface bowlders. These serve to indicate its limits in places where the topographic expression is weak. They are largely granitic rocks, though many other Canadian crystallines are represented. The bowlders do not seem to be so numerous beneath the surface; at least there are but few exposed in the banks or bluffs of the streams and they are seldom struck in the excavation of wells.

OUTER BORDER DRAINAGE.

The position of the ice margin at the time this moraine was forming was very unfavorable for such a southward discharge of glacial waters as took place in connection with the deposition of earlier moraines. Southward discharge could have been accomplished only by a ponding of waters south of the ice margin to sufficient height to raise the water surface to the level of the passes across the divide. This would demand lakes about 400

feet deep in much of the portion west of Cattaraugus Creek, while in the portion east a depth of 200 feet or more would be required simply to carry the water southward to the creek. The conditions were far more favorable for westward discharge from Cattaraugus Creek along the face of the escarpment than across these passes, and there is not wanting evidence of such a discharge. As to the drainage of the region that lies north of Cattaraugus Creek less has been determined. It is not known whether the waters were ponded sufficiently to throw the drainage into Cattaraugus Creek or had lower lines of discharge along or beneath the ice margin.

Strong indications of a westward discharge from the western part of the moraine are found on the slope of the northward projecting part of the escarpment east of Forestville. A well-defined channel or scourway leads across from Silver Creek to Walnut Creek, and is utilized by the Erie Railway for a couple of miles about midway between Smith Mills and Forestville, as indicated in Pl. XIX. It stands between the 920- and 940-foot contours, and is therefore 80 feet or more above the level of the Belmore beach. It harmonizes well, however, with a delta on Walnut Creek at the village of Forestville, which stands between 900 and 920 feet. There are some indications of stream action along the base of the escarpment for 3 or 4 miles west of Walnut Creek, which seem referable to glacial drainage, while the ice margin occupied the district immediately north of the escarpment. The level of Lake Whittlesey was probably reached within a few miles west of Walnut Creek. These channels are now (season of 1900) under investigation by Fairchild.

Between Smith Mills and Cattaraugus Creek the writer noted short sections of an east-west channel and also shelves or terraces leading across divides between streams that now discharge northward; but the full relations of these channels and terraces to the glacial drainage were not determined.

The writer also noted what appears to have been a line of glacial drainage across the projecting part of the escarpment near Smith Mills at a still higher level than the channel above noted, there being a conspicuous terrace at and west of the railway station at about 1,000 feet. This terrace may be mainly a rock shelf whose origin is independent of the glacial drainage, but its smoothness suggests the action of a current It contrasts strikingly with the irregular surface of the slope above this level.

INNER BORDER PHENOMENA.

From the western terminus eastward to Cattaraugus Creek this moraine is followed closely by the Belmore beach, but farther east the beach bears away from the moraine, its course being through the low country, while the moraine rises to somewhat elevated country. The Hamburg moraine, which leads eastward from the village of Hamburg, lies, throughout its course, only a few miles north of the Gowanda, but is entirely distinct from it. Between the two moraines there is a strip in which the drift shows but little aggregation in knolls and is on the whole a thinner deposit than on either moraine. The most conspicuous development of morainic topography is near the mouth of Cattaraugus Creek, as indicated above. On some of the high ridges the drift is so thin that shallow ditches reach the rock, which in places is touched by the plow. In the valleys the drift is very thick, there being nearly as much as on the bordering moraines. Bowlders are much less conspicuous on this tract than on the Gowanda moraine, but otherwise the drift is not strikingly different in the two situations.

The beaches and attendant lake features are discussed farther on. We therefore pass directly to the Hamburg moraine.

HAMBURG MORAINE.

DISTRIBUTION.

The Hamburg moraine has not been recognized west of the village of Hamburg, N. Y., which is situated 10 miles south of the city of Buffalo. It seems probable, however, that the ice margin extended westward from Hamburg along the north side of Eighteenmile Creek to Lake Erie. Possibly the somewhat indirect westward course of the creek will prove to be due to the presence, along its north side, of a water-laid morainic ridge so broad and low as to be scarcely perceptible and yet of sufficient relief to prevent the stream from taking the more direct course northwestward into Lake Erie.

At Hamburg a distinct till ridge appears near the level of the upper beach of the Lake Warren series and leads northeastward to Orchard Park, where it is crossed by the Belmore beach. From Orchard Park the course is eastward across Cazenovia Creek to the north edge of East Aurora, and thence to Buffalo Creek, the outer border in Buffalo Creek Valley being at Porterville, and the inner border near East Elma. In the 15 miles from

Hamburg to Buffalo Creek the moraine increases from less than a mile to fully 3 miles in width. East from Buffalo Creek it becomes still wider, and in eastern Marilla Township has two somewhat distinct members, one of which passes south of Williston, and the other north. The Hamburg moraine connects with the interlobate moraine of the Lake Escarpment system in the northwestern part of Wyoming County. Its length from Hamburg to the interlobate moraine is scarcely 25 miles, and if extended westward to Lake Erie it would not much exceed 30 miles.

RANGE IN ALTITUDE.

The crest of the moraine at Hamburg stands 825 feet above tide. It rises to about 875 feet at Orchard Park, and to fully 1,000 feet between Orchard Park and Cazenovia Creek. Between Cazenovia and Buffalo creeks its outer border stands 925 to 950 feet above tide, but the highest points in the midst of the moraine are probably above 1,000 feet. From Buffalo Creek eastward the inner border rises from about 950 feet to nearly 1,000 feet, and the northern, or inner, member has a crest reaching 1,000 feet near the meridian of Williston, and becoming still higher at its junction with the interlobate moraine. The inner member reaches about 1,100 feet on the meridian of Williston, and perhaps 1,200 feet at its junction with the interlobate moraine.

TOPOGRAPHY.

The greater part of the moraine consists of sharp knolls 20 to 50 feet in height, which, together with inclosed basins and winding sloughs, give it very strong expression. The most inconspicuous part is the crest and outer slope of the western portion, from near Orchard Park to Hamburg, where only gentle swells 5 to 10 feet in height occur. The sharp knolls are usually closely aggregated, but in Marilla Township the outer member consists of scattered knolls of considerable prominence, among which are nearly plane tracts which occupy more ground than the knolls. The inner member, as far west as Marilla, has closely aggregated sharp knolls. But from Marilla to East Elma there is a pitted gravel plain with basins 10 to 20 feet or more in depth, which often cover several acres each. The width of this strip is a mile or more, and its length about 3 miles. It stands very near the level of the Belmore beach, and was apparently formed in the water.

On the inner slope of the moraine near Orchard Park the lake waves connected with the Belmore beach have formed a marked terrace from which the knolls have been cut away and the depressions filled, but westward from Orchard Park down the slope toward the upper beach of the Lake Warren series, the knolls and basins seem to have been modified but little by lake waves. The moraine appears to have extended but little north of the beach, though a few drift knolls were observed a mile or so north of it along the valley of Rush Creek. A small part of the moraine, about 2 miles southwest of Orchard Park, stands as an island above the level of the Belmore beach. It covers only about 40 acres, and the road from Abbotts Corners to Ellicott passes directly over it. Wave action is very clear on its north and west face, but the south and east are scarcely at all wave-cut. These and other features attending the lake occupancy are more fully discussed in connection with the beaches.

STRUCTURE OF THE DRIFT.

This moraine contains a remarkably large amount of gravelly material along much of its course. There is, however, from Hamburg nearly to Orchard Park, a ridge of compact clayey till forming the crest of the moraine. There is also much compact till on the high parts of the moraine between Cazenovia and Buffalo creeks. Gravelly knolls abound on the inner slope from near Hamburg to Orchard Park immediately north of the till ridge just mentioned, while from Orchard Park to Cazenovia Creek the crest, as well as slopes, is largely a gravelly material. There is an abandoned valley, probably of preglacial age, leading from Cazenovia Creek at East Aurora to Buffalo Creek at East Elma, and this is filled with sharp gravelly knolls and ridges, which are markedly in contrast with the gentle till swells on the higher part of the moraine north of this old valley. From Buffalo Creek eastward nearly all the knolls appear to contain gravel, while the low or gently undulating tracts among them carry a rather stony till.

OUTER BORDER DRAINAGE.

The line of escape for glacial waters at the time this moraine was forming was evidently westward into the glacial lake which was bordered by the Belmore beach (Lake Whittlesey). There is a well-defined channel leading from the head of Little Buffalo Creek, in southeastern Marilla

Township, in a course south of west along the outer border of the Hamburg moraine to Buffalo Creek, just below Wales Center. Its altitude is fully 100 feet above the present bed of Buffalo Creek at Wales Center, or not far from 1,000 feet above tide. Upon reaching Buffalo Creek, the stream seems to have passed down the valley about two miles, or nearly to Portersville, and then turned westward along the face of the upland that separates Buffalo Creek from the abandoned valley leading in from East Aurora. It soon entered that abandoned valley and followed it in a course south of west through East Aurora to Cazenovia Creek. Its altitude near the railway station in East Aurora is about the same as the station—925 feet. Its precise course for 2 or 3 miles west from Cazenovia Creek has not been determined, but it seems to have kept along the creek far enough to pass the elevated upland west of East Aurora, and to have then taken a southwestward course along the outer border of the moraine. Evidence that it took this course is found in a channel, now abandoned, whose south bluff is well defined, being cut into the face of the escarpment south of the moraine, but whose north border is vague. The east-west road leading from East Aurora to Deuels Corners descends into this channel about 2 miles east of Deuels Corners and keeps in it for about a mile toward the corners, when low shale hills set in. The channel passes between these hills and the higher land to the south, and has for a short distance a well-defined bluff on each side. West of the shale hills it enters the old lake at an altitude about 875 feet above tide, thus making a fall of 50 feet in the 6 or 7 miles west from East Aurora. The actual fall of the stream was, however, somewhat less, for northeastward differential uplift, as shown in the neighboring beaches, has materially affected that region.

The channel just described is but one-fourth to one-half mile wide, and its bluffs seldom exceed 30 feet in height. It seems rather small to have carried the full drainage from the melting ice sheet, and suggests the interpretation that part of the water may have worked westward into the lake beneath the edge of the ice sheet.

Between the two members of the moraine in eastern Marilla Township there is a small channel which leads westward past Williston to the pitted gravel plain south of Marilla. This was apparently formed by a glacial stream, for it is out of harmony with the present drainage and is largely an abandoned channel.

There is still another channel which seems to have been formed just before the ice sheet withdrew from this moraine. It lies on the north slope of the inner member, but is limited on the north by a chain of drift knolls that separates it from a lower channel. Each of the channels passes across from Cayuga Creek to Little Buffalo Creek. The one under discussion seems to be in harmony with the Belmore beach and apparently connected with Lake Whittlesey at Marilla. The lower channel to the north seems to be connected with the upper beach of the Lake Warren series and is therefore of later date than this moraine.

MARILLA MORAINE.

DISTRIBUTION.

The Marilla moraine appears to set in on the east side of Little Buffalo Creek immediately north of the village of Marilla in eastern Erie County, N. Y. If it continues farther west, it is either too faint to be easily recognized or is combined with the Hamburg moraine. From Marilla eastward into Genesee County it is a well-defined ridge separated by only a narrow, valley-like lowland from the Hamburg moraine. Its outer border passes just north of the corners of Wyoming, Genesee, and Erie counties, while its inner border passes from Erie into Genesee County immediately east of the village of Alden.

The Marilla moraine does not, like the Hamburg, connect with the interlobate moraine of the Lake Escarpment system, but passes the north end of the interlobate spur and continues eastward to Tonawanda Creek Valley south of Batavia, near which it passes beneath or becomes combined with the Batavia moraine. For several miles before reaching Tonawanda Creek it is combined with the Alden moraine, which farther west lies 1 to 3 miles north of it.

The moraine is generally between 1 and 2 miles wide. Its course throughout is from south of west to north of east and is remarkably direct.

RANGE IN ALTITUDE.

This moraine shows remarkably little range in altitude compared with moraines to the south. Its altitude near Marilla is about 900 feet on the crest and 875 feet on the inner border; at the line of Erie and Genesee counties the crest is about 1,000 feet; from this county line eastward to

Tonawanda Creek the crest generally stands between 950 and 1,000 feet, while the inner border in places extends down to less than 900 feet.

TOPOGRAPHY.

Along this moraine there is generally a definite ridging in line with the trend of the moraine. In places two or more parallel ridges appear in close succession, but quite as often there is a single main ridge, on the inner slope of which there may be subordinate ridges. The relief of the ridges seldom exceeds 40 feet, and is generally 30 feet or less.

The undulations range from low, gentle swells to rather sharp knolls West from the Erie-Genesee county line the crest is in places nearly free from swells, and there are very few sharp knolls; but in Genesee County the surface is generally sharply undulating, with knolls 15 to 30 feet in height, which cover but a few acres each. The knolls are also more closely associated in Genesee than in Erie County. There are only a few well-defined basins, but winding sloughs are common among the knolls.

There is a small esker situated in this moraine in the northeast part of Darien Township, Genesee County. It is less than a half mile long and only 50 to 75 feet wide, yet it rises generally to a height of fully 15 feet. The trend is nearly north to south, though the esker is slightly winding. It terminates at the south in a small gravel delta, which stands about as high as the crest of the ridge. This delta rises abruptly above low ground on the east, but is continued toward the west in a gravel plain which is at nearly the same level as the delta, and which is probably an outwash from the portion of the ice sheet immediately west of the esker, it being on the south border of the moraine.

STRUCTURE OF THE DRIFT.

The Marilla moraine carries much less gravel than the Hamburg, there being only an occasional knoll in which gravel is known to occur. The surface of the moraine, both on knolls and in depressions, is a rather clayey till, liberally strewn with bowlders. Large limestone slabs, gathered from the formations which outcrop between this moraine and Lake Ontario, are conspicuous both on the surface and in the midst of the till. Such slabs are rare on moraines outside of this one, but are common on those which lie between it and the lake.

RELATION TO LAKE WHITTLESEY

This moraine seems to have been formed nearly at the time when the lake level dropped from the Belmore beach to the Forest, and marks, therefore, the closing part of the existence of Lake Whittlesey. Taylor and the writer, after tracing the Belmore beach to Marilla, searched in vain for its continuation on the north slope of the Marilla moraine. That slope appears not to be modified by lake waves at the level of the Belmore beach. This matter is considered more fully in connection with the discussion of the Belmore beach.

OUTER BORDER DRAINAGE.

Along the south border of the western portion of the moraine, from southwestern Darien Township, in Genesee County, to the end of the moraine, near Marilla, there is an open valley occupied in part by an eastern tributary of Cayuga Creek, in part by Little Buffalo Creek, and in part abandoned. It shows a perceptible westward descent, and was evidently utilized by the glacial waters in their escape to the lake, if it was not opened by them. The width ranges from about one-fourth mile up to over one-half mile. The banks are usually low, being seldom more than 30 feet in height. At Marilla it is a few feet lower than the Belmore beach, and the valley continues descending westward till it reaches the level of the Forest beach, where an extensive delta is found that covers the interval between Little Buffalo and Buffalo creeks. It seems evident that by the time this channel was fully opened the lake level had dropped to the Forest beach and Lake Warren had succeeded Lake Whittlesey in the Erie Basin.

From the head of the eastern tributary of Cayuga Creek, just referred to, eastward to Tonawanda Creek the line or lines of escape for glacial waters have not been clearly worked out. There are scourways among the glacial ridges and knolls in northern Darien Township which appear to mark lines of discharge, and which may, by detailed study, be found to form a connected system. These may, however, have been opened at the time the ice sheet was forming the Alden moraine, which, as above noted, is combined with the Hamburg from Darien Township eastward. This being the case, they do not throw light on the earlier part of the drainage. From eastern Darien Township eastward to Tonawanda Creek there is a sag or valley along the outer border of the moraine, which received some

outwash, but which may not have been excavated by glacial waters. The esker delta noted above lies in this sag, and its form seems to indicate that it was built up in a body of still water or in a stream with very sluggish current The gravelly outwash to the west of the esker delta and the delta itself indicate that currents of considerable strength were issuing from the ice sheet; but these were, perhaps, forced out by hydrostatic pressure into a body of water which had but little current.

ALDEN MORAINE.

DISTRIBUTION.

The Alden moraine has been recognized no farther west than Alden Center, in eastern Erie County, N. Y. It appears as a well-defined ridge immediately east of Alden Center on the east bluff of Ellicott Creek and just back of the lower or Forest-Crittenden beach of Lake Warren. It takes a course north of east into Genesee County, and, as above noted, becomes united with the Marilla moraine about 3 miles east of the county line. Its inner border at the west end is south of the Lackawanna Railroad, but the moraine soon crosses to the north side of that railroad and lies near the Lehigh Valley and New York Central railroads. For 2 or 3 miles in northern Darien and southern Pembroke townships, Genesee County, it extends slightly beyond (north of) the New York Central Railroad, but with this exception it lies south of that railroad to the valley of Tonawanda Creek in Batavia. The Batavia moraine there comes in from the northwest and overrides or combines with the Alden moraine, and it has not been recognized between Batavia and the eastern limits of our district, the Genesee River.

RANGE IN ALTITUDE.

This moraine, like the Marilla, presents but little range in altitude; the western end, near Alden Center, stands about 850 feet above tide, and there are but few points between that place and Batavia that rise above 950 feet.

TOPOGRAPHY.

The greater part of this moraine is very similar in contour to the Marilla moraine, there being generally a definite ridging from east to west in line with the moraine. The ridges are not continuous for long distances, so that drainage lines find frequent gaps through which to pass northward.

The knolls that are associated with the ridges are often quite sharp, but are only 10 to 30 feet in height.

At the western end of the moraine there are numerous small basins bordered by gently undulating gravelly tracts. The appearance is somewhat similar to that of the pitted gravel plains found as an outwash from the ice sheet. The outwash seems to have been directly into lake water, for the pitted plain stands at about the level of the beach of Lake Warren.

STRUCTURE OF THE DRIFT.

In structure the Alden moraine is similar to the Marilla, the greater part of the drift being a clayey till. Limestone pebbles and also large blocks are conspicuous ingredients of the till, and surface bowlders are numerous.

OUTER BORDER DRAINAGE.

It is probable that the glacial drainage from the vicinity of Tonawanda Creek to the western terminus of the moraine was westward. For a few miles it was through narrow channels among the knolls and ridges of the Marilla moraine; but from near Fargo, in Darien Township, Genesee County, westward to Alden Center, there is a plain 1 to 2 miles in width which stands near the level of Lake Warren, and which probably carried a shallow bay into which the glacial waters discharged.

RELATION TO LAKE WARREN.

To the north and east from this moraine there seems to be but a single beach of Lake Warren, the Lower Forest or Crittenden, while to the south and west there is a more complex system. The moraine seems therefore to correlate with a somewhat lengthy part of the Lake Warren history. This matter is considered more fully in the discussion of the beaches of Lake Warren.

PEMBROKE RIDGES.

DISTRIBUTION.

Under this name is discussed a complex system of sharp gravelly knolls and ridges which leads eastward from the west part of Pembroke Township, in western Genesee County, to the Batavia moraine in western Batavia Township, a distance of about 10 miles. They are in part shown on Pl. III. There are usually two, and in places three, ranges of knolls, each trending

from south of west to north of east. The southern range lies only 1 to 2 miles north of the inner border of the Alden moraine. The second range lies 1 to 2 miles farther north. The second range crosses to the north side of Tonawanda Creek near East Pembroke, while the south range lies south of the creek all the way to the Batavia moraine. There is a short range of knolls south of Indian Falls, which is fully 2 miles north of the second range. A range west of East Pembroke is also somewhat distinct from the second range, and trends from southwest to northeast.

These ranges of knolls may find westward continuation toward Buffalo along the Corniferous escarpment, there being a few drift knolls and short ridges scattered along the base of the escarpment from Akron westward, and a few knolls on the escarpment between Akron and Crittenden. These knolls along the base of the escarpment may, however, be incident to the retarding influence of the escarpment upon the ice movement, in which case they may indicate nothing as to the position of the ice margin.

RANGE IN ALTITUDE.

The highest point in this system of knolls is in a gravel ridge on the north side of Tonawanda Creek, about 2 miles northeast of East Pembroke, which bears some resemblance to an esker. This ridge, as shown by the Medina topographic sheet, rises above the 1,000-foot contour. It is 75 to 100 feet higher than the majority of the knolls in that vicinity, and stands 130 feet above low ground within one-fourth of a mile to the east, north, or west. The crests of the two ranges generally stand between 900 and 950 feet, while the low ground on their borders is about 850 to 875 feet.

TOPOGRAPHY.

The south range of knolls is in places scarcely one-fourth of a mile in width, though the knolls rise 30 to 50 feet above bordering plane tracts. There are scattering knolls along the north border of this range which are but 10 to 15 feet high. The range has, on the whole, greater continuity than the one north of it, but is not so prominent. The north range contains several knolls 75 feet or more in height and many are 40 to 50 feet. It is so prominent that its course may be seen for several miles at a stretch. Some of the knolls are sharp and conical; others are elongated, though seldom to a greater length than one-fourth of a mile. The large knolls carry hummocks on their slopes and also send out irregular spurs, which add

to the complexity of the range. The portion on the north side of Tonawanda Creek lies within the limits of the Medina quadrangle and occupies the interval between the creek and a marshy tract nearly parallel with it a mile or so to the north (see Pl. III). The most prominent group of knolls in this part of the range bears some resemblance to an esker, in that it trends directly across the range and has a sharp, narrow gravel ridge. The ridge has not, however, so smooth a crest and slopes as generally characterize eskers. The north end rises abruptly to a height 130 feet above the bordering marsh, but most of the ridge is only 75 to 90 feet above the marsh. It is about a mile in length and is narrow and sharp throughout its course. The knolls around this esker-like ridge are generally but 20 to 30 feet high, being less prominent than in the part of the range farther west, on the south side of Tonawanda Creek.

The range standing south of Indian Falls is less than a mile in length and scarcely one-fourth mile in width, but stands nearly 50 feet above bordering tracts on the south and east, and even more above the tract on the north. From this range southward to the main range there is a gently undulating strip strewn with bowlders, that separates the old lake plain on the west from a shallow bay on the east which occupied 3 or 4 square miles.

STRUCTURE OF THE DRIFT.

So far as can be ascertained from the surface ditches and shallow excavations, these ranges of knolls are composed of gravelly and sandy material with but little clayey till. They are in striking contrast to the Alden and Marilla moraines, which, as above noted, are composed largely of clayey till. There are numerous surface bowlders, but there seems not to be many bowlders incorporated in the drift.

The cause for so much water action in connection with the production of this moraine is not apparent. It does not seem due solely to its having been formed near the level of Lake Warren, for in that case we should expect the Alden and Marilla moraines to show evidence of more water action.

OUTER BORDER DRAINAGE.

There is a sag along the outer border of the south range extending from its western end at the shore of Lake Warren eastward nearly to Batavia, which affords adequate room for westward discharge of glacial

waters. It is now utilized for a few miles by Murder Creek. The sag stands but little above the old lake level, and probably was in part occupied by a bay at the level of the lake.

There is also a sag between the south and north ranges which would have afforded a line of discharge for glacial waters issuing from the north range. It is now utilized from near East Pembroke westward by a tributary of Murder Creek, while Tonawanda Creek utilizes the part east of East Pembroke.

BATAVIA MORAINE.

DISTRIBUTION.

The Batavia moraine forms the south member of a rather complex series of moraines, drumlins, and eskers, which occupy the district immediately south of Lake Ontario. The writer applied the name Lockport to this south member some years ago,[1] but upon further consideration it seems preferable to substitute the name Batavia. The western part is so vague that some uncertainty is felt as to its continuation. The Batavia moraine, from the Genesee River westward to the Tonawanda swamp in northwestern Genesee County, lies just south of the drumlin belt and has a general course slightly north of west. From that swamp westward two lines invite attention: one continues the course north of west to Lockport, passing to the north side of the few drumlins which appear in that region; the other leads south of west along or near the base of the Corniferous escarpment toward Buffalo, keeping south of all the drumlins. The latter course seems to have in its favor a relationship to the drumlins similar to that found farther east. It, however, differs in being not even approximately at a right angle with the trend of the drumlins, but instead is nearly in line with them. So far as morainic features are concerned, there is very little to favor this line, there being only occasional slight ridging and a few knolls and basins; and these, as already indicated, may be incident to the retarding influence of the escarpment upon the ice movement rather than marginal accumulations of a morainic character.

While the uncertainty as to this line is great, it should perhaps be held as a possible continuation of the ice margin, especially since the line toward Lockport seems also open to question. Turning to the latter line we find

[1] Am. Jour. Sci., 3d series, Vol. L, 1895, pp. 13–17.

that there is a definite belt of ridges and knolls leading from the Tonawanda Swamp toward Lockport, which seemed to the writer, while in the field, to be the more probable continuation of the Batavia moraine. The gap at the Tonawanda Swamp, which separates it from that moraine, is less than 2 miles wide, and the ridges on opposite sides of the swamp are about in line with each other, as may be seen by reference to Pl. III. It is found, however, that the north or main ridge of the belt west of the swamp is practically continuous with the Barre moraine, which leads in from the east along the north side of the drumlin belt. This may not oppose the interpretation that the belt constitutes the continuation of both moraines, but it certainly leaves it open to question. The description of the Batavia moraine will consequently be carried eastward only from Tonawanda Swamp, the portion of the morainic system to the west being described in connection with the Barre moraine.

The Batavia moraine, as shown in Pl. III, leads from the southeast border of Tonawanda Swamp southeastward across Alabama Township, Genesee County, passing south of Alabama Center and Smithville and coming to the Corniferous escarpment immediately south of the latter village. On rising to the brow of the Corniferous escarpment it leads toward Batavia and crosses over or becomes combined with the Pembroke, Alden, and Marilla moraines. From Batavia it continues south of east as far as Oatka or Allens Creek, which it crosses 2 to 4 miles south of Leroy. It then takes a course nearly east to the Genesee River, coming to that stream immediately below (north of) the village of Avon. Its farther course was not determined.

RANGE IN ALTITUDE.

The Tonawanda Swamp is about 620 feet above tide. The altitude increases gradually from the swamp to the Corniferous escarpment, reaching about 780 feet at the base and 900 feet at the brow of the escarpment south of Smithville. The highest points between Smithville and Batavia are about 960 feet, one being at the geodetic station 4 miles west of Batavia, and others between that place and the city. An altitude of 900 to 950 feet prevails for several miles east from Batavia. The moraine then begins to descend toward the Genesee River, and is below 600 feet on the border of that stream.

TOPOGRAPHY.

On the east border of Tonawanda Swamp the moraine rises into a stout till ridge 30 to 50 feet in height, which has a well-defined crest and gently undulating surface and is a prominent feature for at least 4 miles Its contours are to some extent shown on the topographic map, Pl. III.

Upon rising to the Corniferous escarpment the moraine breaks up into a series of knolls and short ridges, rather sharp in contour, which inclose basins and winding sloughs. This phase becomes conspicuous at the place where the moraine rises above the level of Lake Warren, though a few knolls and basins appear southwest of Oakfield at a considerably lower level. The northwest side of this till ridge, just discussed, is fully 200 feet below the level of that lake, and is a remarkably strong feature to have been formed in such a depth of water. The contours of the part of this moraine which was formed above the level of Lake Warren are partly brought out by the topographic maps, the course of the moraine being through the northeast part of the Medina quadrangle and the southwest part of the Batavia. It will be observed that the height of the knolls and ridges ranges from 60 feet down to less than 20 feet. Many small knolls less than 10 feet in height are not represented on the maps, and this detracts greatly from their expression.

The moraine holds its sharp features as far east as the valley of Allens Creek, near Leroy, but within a few miles east from that creek the sharp knolls change to very small swells and the prominent knolls and ridges present smoother slopes than to the west. The ridges are not so long nor so definite as in the district below the Corniferous escarpment, but they are fully as high. This part of the moraine was also formed in water, for a glacial lake occupied the Genesee Valley at the time it was forming.

STRUCTURE OF THE DRIFT.

The portion of the Batavia moraine between the Corniferous escarpment and the Tonawanda Swamp contains a large amount of compact till, but the portion on the escarpment carries a loose stony till and also considerable gravel and sand. The gravelly ingredients are more conspicuous from Batavia northwest to the brow of the escarpment than east from that city. The portion of the moraine which stood above the level of Lake Warren carries a large number of surface bowlders, but bowlders are not a conspicuous feature on the part formed below the level of the lake.

WESTERN NEW YORK DRUMLIN BELT.

DISTRIBUTION.

The extent of the drumlin belt from the Genesee River westward to Niagara River is well shown on the Rochester, Brockport, Albion, Medina, Lockport, and Tonawanda topographic sheets, incorporated in Pl. III, the contours of the oval-shaped hills being a sufficient means for identification. The drumlins are all situated in the district between the Corniferous and Niagara escarpments.[1] It will be observed that in the Rochester quadrangle the drumlin belt crosses to the west side of the Genesee below Scottsville, and nearly occupies the interval of 7 miles between Allens Creek and Black Creek; on the Brockport quadrangle the south border lies near Allens Creek, while the north border is 6 to 8 miles farther north, being generally about 2 miles north of Black Creek; in the Albion quadrangle it lies mainly in the northern townships of Genesee County (Bergen, Byron, Elba, and Oakfield), but extends southward into Stafford Township, in the vicinity of the New York Central Railroad; in the Medina sheet it is represented in only a few small drumlins on the south side of Oak Orchard Swamp, in Oakfield and Alabama townships. There is an interval of about 15 miles in which no drumlins occur; but near Raymond, south of Lockport, there is a group of three drumlins; and near Pendleton Center, a few miles farther west, there is a similar group, and still farther west, near Tonawanda, an occasional low drumlinoid ridge.

Where best developed the drumlins occur at intervals of one-half mile to a mile, and there is usually a nearly plane surface among them, but where they are poorly developed the drift among the drumlins is liable to be aggregated in knolls of irregular shape, often bearing no resemblance to drumlins. The drumlins prevail to the exclusion of other drift knolls only in very limited areas. It will be observed that they are most abundant in the northern and eastern parts of Elba Township, Genesee County, and thence eastward along the borders of Black Creek to the Genesee River. In the southern part of the drumlin belt there are many small drift knolls and ridges which do not appear on the topographic sheets, but which tend to give the surface a morainic appearance. The

[1] A few drumlins near the mouth of Genesee River do not fall in the belt under discussion.

drumlins near Lockport and farther west stand in a very level region, decidedly in contrast to that found in the drumlin belt to the east.

RANGE IN ALTITUDE.

Although the drumlins of this belt are all situated in the district between the Niagara and Corniferous escarpments, the belt shows a range of about 300 feet in altitude. They appear at the lowest altitude near the Genesee River, 525 to 550 feet, and at the highest altitude in eastern Elba and northern Stafford townships in the Albion quadrangle, where their crests, in a few instances, rise above the 820-foot contour. It should, perhaps, be explained that there are other drumlins near the shore of Lake Ontario (some of which appear in Pl. III) that are not in the belt under discussion.

TOPOGRAPHY.

The usual form assumed by the drumlins in this region is an elliptical smooth-surfaced knoll, a mile or less in length and scarcely one-fourth mile in width, but in places they are elongated to 10 or 12 times their width and reach a length of 2 miles or more. They trend in a general northeast-southwest direction, with variations of perhaps 20° on either side of a due northeast-to-southwest line. The northeast end shows a tendency to be more abrupt than the southwest, though a large proportion of the drumlins are very symmetrical. Where the sides are not symmetrical the southeast is usually the more abrupt. The height ranges from 10 or 15 feet up to about 100 feet, but in the majority it is not far from 40 feet. The most prominent drumlins are in northern Elba Township, the one utilized for the Parker geodetic station being about 105 feet above the Oak Orchard Swamp, only one-fourth mile to the north. Two miles farther west a knoll of gravelly constitution and less regular form than the typical drumlin stands 130 feet above the bordering swamp.

The knolls and ridges which occur among the drumlins and along the south border of the belt are of various shapes and sizes, as may be seen to some extent in Pl. III. There are with these knolls and ridges small, nearly plane areas carrying shallow basins. Such areas are usually gravelly, and present the appearance of the pitted outwash plains that border moraines. These pitted plains occur at intervals along the north side of Allens Creek from Scottsville westward to the bend north of

Leroy. They are also conspicuous in the vicinity of Oakfield. In general they are near the south border of the drumlin belt, and, together with the neighboring drift knolls and ridges of morainic type, they support the view that the ice margin at one time stood near a line drawn along the southern edge of the drumlin belt. This interpretation is strengthened by the fact that an exceptionally large number of bowlders occur throughout the drumlin belt from the Genesee River westward to the point where it dies out in western Genesee County. They abound among the drumlins as well as on them, and on nearly plane tracts as well as on knolls.

STRUCTURE OF THE DRIFT.

The drumlins are usually composed of a compact blue till, and it is rare to find assorted material in them. Some of the most prominent ones, however, are known to contain gravel. From the numerous well sections obtained it would appear that the drumlins rarely if ever have a rock nucleus. In many cases the wells extend far below the base of a drumlin without entering rock.

For several miles west from the Genesee River the drumlins carry a coating of fine sand, deposited apparently by lake water after the withdrawal of the ice sheet. In some cases the depth of the sand is several feet, but it is usually only a few inches. The heaviest deposits noted are those lying on the west side of Genesee River, north of Scottsville.

The knolls and much of the plane-surfaced drift among the drumlins contain a large amount of gravel with the till. This is especially the case in the southern part of the belt. The presence of gravel is known chiefly from well data, but there are a number of places where gravel pits have been opened.

The bowlders are apparently more numerous on the surface than beneath, at least wells seldom encounter them. They are so abundant on the surface as to afford material for many miles of wall fence, and are also piled in large heaps in the fields. The majority are granite rocks, but slabs of limestone are rather common. In size there is considerable variation from place to place, there being in some localities only small stones a foot or less in diameter, while in others many large bowlders are present. These variations are probably significant, but like the variations in the underlying drift, the significance is not yet apparent.

RELATION TO LAKE WARREN.

After forming the Batavia moraine the ice sheet apparently withdrew from the Corniferous escarpment sufficiently to allow the waters of the Genesee glacial lake to enter Lake Warren and take the level of that lake. This blending of the lakes in all probability occurred while the drumlins and their attendant morainic phenomena were being produced, and the connecting portion of the beach of Lake Warren would date from this time. Possibly the lake waters were barred out or were of little effect for a considerable part of the time that the drumlins were forming, for drumlins were apparently submarginal rather than terminal accumulations of the ice sheet; but the southern portion of the belt, with its morainic knolls and pitted gravel plains, seems to have been nearly coincident with the ice margin for at least part of the time.

It is a matter of much significance that these pitted gravel plains appear at levels far below the level of Lake Warren and in positions where it would seem probable that the lake had free access to the ice margin. Those near Oakfield are fully 100 feet below the level of the neighboring part of the beach of Lake Warren, while those along the border of Allens Creek are 150 to 250 feet or more below the beach. There is a gravel plain just west of Scottsville on the north side of Allens Creek which stands between the 580 and 600 foot contours, or about 275 feet below the beach of Lake Warren. This has been extensively opened for gravel in a direction favorable for showing the mode of formation, there being a pit about one-fourth of a mile long extending from north to south across the gravel plain. The bedding shows that it was built by a stream moving southward away from the ice sheet but up the Genesee Valley. The beds were built out from north to south in the form of a delta, the topset and foreset beds being well exposed. The dip of the foreset beds is most abrupt in the middle part of the pit, being 25° to 30° below the horizontal. With the advance of the delta southward the angle of dip decreases to 10° or less. The material is a sandy gravel with many stones 2 or 3 inches in diameter. It is, on the whole, finer and less distinctly assorted than in the outwash gravels formed in situations where the water had free escape. If Lake Warren still persisted the material contained in this delta and other gravelly deposits along the southern border of the drumlin belt seems likely to have been forced out by hydrostatic pressure from the edge of the ice sheet into the bordering lake.

Excavations in the pitted plain southwest of Oakfield, near the Fertilizer Works, show till interbedded with gravel and sand in such manner as to suggest either a readvance of the ice to form the till, or the deposition of the gravel beneath the ice margin. The form of the pits or basins seems to favor the view that the ice was present and prevented their being filled with gravel. The gravel deposits of this region, while presenting considerable similarity to the outwash found in localities where there was free discharge for the glacial waters will probably, upon close inspection, reveal throughout their extent features which are compatible with the obstructed drainage due to the presence of the waters of Lake Warren.

BARRE MORAINE AND ASSOCIATED ESKERS.

DISTRIBUTION.

The Barre moraine presents a nearly continuous chain of ridges from the head of Oak Orchard Swamp, near South Barre, in southern Orleans County, westward to Lockport. Its crest passes through the villages of West Barre, East Shelby, Royalton, and McNalls, in a slightly winding course, as shown on Pl. III. From its crest eskers and morainic spurs extend north a mile or two, but the main ridge is only about one-fourth of a mile in width. South from the main ridge in western Orleans County small ridges and knolls are scattered over the interval between the ridge and Oak Orchard Swamp. Knolls and ridges also lie south of the main ridge in Niagara County out to a distance of about 2 miles. Those in Niagara County, as above indicated, may belong to the Batavia moraine. The continuation from Lockport seems to be in a northward course toward Wilson, on the shore of Lake Ontario, there being an exceptionally large number of bowlders in that direction. No sharply outlined ridges or other morainic features were noted, but as the drift here was laid down in a great depth of lake water such ridges could hardly be expected.

From South Barre eastward the course of the Barre moraine is rather indefinite. There is, however, a prominent group of knolls in the "New Guinea Settlement" at the head of Oak Orchard Swamp, in southwestern Clarendon Township, which constitutes a natural line of continuation. From this group the course seems to be south of east into northeastern Genesee County, there being more drift knolls in that direction than to the east or northeast. Its continuation in Monroe County seems to be in knolls near the line of Ogden and Riga townships and in the north part of Chili

Township. This belt of knolls is situated immediately north of the north border of the drumlin belt from near the "New Guinea Settlement" eastward to the Genesee River, and presents a strikingly different topography, as may be seen by the topographic sheets and to some extent in Pl III. The number of knolls is greater than in the district to the north, though the latter is by no means free from them.

RANGE IN ALTITUDE.

The principal variation in altitude is made in rising from the plain north of the Niagara escarpment up to the brow, the altitude near the base being only 400 feet and on the brow about 630 feet. The level of the base of the drift ridges and knolls from the escarpment eastward to Oak Orchard Creek falls between 620 and 650 feet, while the crests of the ridges range from about 630 feet up to 700 feet, the highest points being near West Shelby. From West Shelby to East Shelby the crest stands generally between 650 and 675 feet, but knolls on a spur north of the main ridge near the Ross geodetic station rise above 700 feet. From East Shelby to West Barre the crest is mainly between the 660- and 680-foot contours, but a point on an esker at the Pusel geodetic station, a mile northwest of West Barre, reaches 737 feet. This appears to be the highest point in Orleans County. From West Barre to South Barre the crests of ridges range between 650 and 700 feet, the lowest ridges being situated in the edge of Oak Orchard Swamp. At the border of the sharp drift knolls in the New Guinea Settlement, the swamp stands just below the 640-foot contour, while some of the knolls rise above the 700-foot contour. From this group of knolls eastward to western Monroe County there is but little descent, the altitude being generally between 620 and 650 feet; but from the meridian of Churchville to the Genesee River, a distance of about 12 miles, there is a descent of almost 100 feet, the altitude on the border of the Genesee being but little above the 520-foot contour.

Particular attention is called to the range in altitude because the narrow ridge leading westward from West Barre has been considered a beach of Lake Ontario by many of the residents. The form and structure in places seem to sustain that interpretation. This is especially true of the part between West Barre and West Shelby; but in this part of the ridge there are oscillations of 30 or 40 feet in the level of the crest within a distance of

less than 5 miles, a difference which seems too great to be due to uplift. Uplift here may amount to a foot or more per mile along a line from southwest to northeast, as shown by measurements on the neighboring portion of the beach of Lake Warren. A variation of 10 to 12 feet may also occur in a shore line, independent of uplift, there being that amount of variation in the beach of Lake Erie. But if these are combined it would cause scarcely half the variation in altitude which this part of the ridge displays.

TOPOGRAPHY.

There are few moraines which present greater variations in topography than are displayed by this one. Knobs and basins, smooth till ridges, eskers, drumlinoid forms, and nondescript or irregular forms are all present.

For a few miles south from Lake Ontario only a few low swells can be detected, but the bowlders which appear in great numbers seem to indicate the position of the ice margin. They occupy a belt 2 miles or more in width, in which they have been heaped in great piles in the fields and built into stone walls.

On the face of the Niagara escarpment for 2 miles east from the eastern edge of the city of Lockport the moraine consists of a series of knolls and basins, which give that part of the escarpment an appearance strikingly in contrast with the smooth face it presents west from Lockport. From the brow of the escarpment about a mile east of the city limits of Lockport a well-defined ridge 15 to 40 feet in height and one-fourth mile or less in width leads eastward past McNalls and Royalton. Its surface is gently undulating, like the till ridges so common on the plains of Illinois, and, like them, it is composed largely of till. To the north, between this ridge and the escarpment, there is a gently undulating tract thickly strewn with bowlders, while along the brow of the escarpment several knolls 15 to 20 feet high appear. South of the till ridge the surface is nearly plane as far east as the meridian of McNalls. A system of knolls and ridges there sets in which leads eastward to West Alabama, and which may belong to the Batavia moraine. The ridges are broken by occasional gaps and are somewhat disjointed, but are definite for 2 or 3 miles at a stretch, as shown by the topographic map (Pl. III) In form they are similar to the ridge that leads through Royalton, but they are also similar to the till ridge southeast of Tonawanda Swamp in Alabama Township, Genesee County, of which they are, perhaps, the continuation.

The main ridge leads from Royalton eastward to West Shelby, but becomes irregular, and at West Shelby connects with a prominent morainic spur which extends north about 2 miles It also changes in constitution to a mixture of gravel and till. In the spur that leads north from West Shelby there are sharp knolls 20 to 40 feet high, among which basins are inclosed that cover areas of from 1 to 5 acres each. It is a very gravelly belt, but there is usually a thin capping of till thickly set with bowlders About a mile east from the north end of this morainic spur is an isolated sharp ridge of sandy till, on which Ryan geodetic station was placed. The ridge is about one-half mile long and trends north-northeast to south-southwest. Its highest points are about 60 feet above the bordering plain. There are knolls 15 to 30 feet high along its slopes.

On the east side of Oak Orchard Creek there is greater complexity than on the west. The main ridge is very definite all the way from the creek to West Barre, but ridges north and south of it are scattered over a nearly plane tract occupying only a small part of the surface. The main ridge in places presents a smooth surface like a beach line and is narrow and low, the height being but 10 to 15 feet and width 50 to 75 yards; but usually its surface is more irregular than a beach line, there being variations of 15 to 20 feet in height within short distances. The bulk is also greater on the whole than beaches commonly display, the width being from an eighth to a fourth of a mile and the height from 10 to 40 feet.

Of the scattering ridges found south of the main ridge the most prominent is at Edwards geodetic station, its height being about 50 feet. The majority are between 15 and 25 feet in height. These ridges are commonly but an eighth of a mile or less in width and one-half mile to a mile or more in length. The usual trend is from north of east to south of west, being similar to that of the drumlins, but this is the only point of resemblance, the surface being less regular than that of drumlins. They also are largely composed of sand and gravel, while the drumlins are mainly of till.

North of the main ridge there are only scattering knolls and low winding ridges for a mile or two east from Oak Orchard Creek. A sharp range of gravelly hills then sets in, which trends northwest to southeast. Its highest points stand 75 to 100 feet above bordering plane tracts and its

surface is very irregular, as may be seen by reference to the topographic map (Pl. III). For several miles east from this range of knolls the surface is nearly all plane, there being only an occasional low knoll. There is then a sharp ridge with north-south trend, which connects at the south near East Shelby with the main ridge. It is about $1\frac{1}{2}$ miles long and one-fourth mile or less in width. Its height ranges from 15 to 60 feet. The surface is thickly strewn with bowlders, which add to its morainic expression. This ridge and the range of gravelly hills to the west seem to be morainic spurs rather than eskers; at least they are not so regular in form as eskers.

The most prominent ridges of Orleans County are found in the next spur to the east. They cover a track nearly 2 miles in length (from north to south) and a mile or less in width. The main ridge bears some resemblance to an esker, but there are many irregular-shaped ridges and knolls associated with it. It terminates at the south in a flat-topped tract which stands about 80 feet above the bordering plains and which incloses a deep basin. A marsh lies in the midst of this system of ridges. There is on the west side of the marsh a ridge about 40 feet in height which has a flattened top in which there are shallow basins. On the east side of the marsh is a less regular ridge, which in places presents the form of an esker.

From West Barre eastward to the east end of Oak Orchard Swamp the ridges and knolls are similar to those found south of the main ridge to the west from West Barre. They trend east-northeast to west-southwest and are rather narrow and sharp. The height is seldom less than 15 feet and in places reaches 40 feet.

The prominent group of ridges and knolls in the New Guinea settlement at the east end of Oak Orchard Swamp is well represented in Pl. III. Basins appear on the crests of the ridges, two of which are shown on the map. The ridges rise abruptly 40 to 60 feet above the bordering swamp.

From this group of ridges eastward to the Genesee River the knolls are rather scattered and of irregular shape. They contrast strikingly with the regular form of the drumlins to the south, as may be seen by reference to the topographic map. Two ridges in this part of the moraine are worthy of notice, one is an esker or gravel ridge near Ogden and the other a sandy ridge near Chili.

East and south of Ogden Village there is a narrow gravel ridge 15 to

30 feet in height and about 2 miles in length, including small gaps. The northern half has a nearly due north-south trend, but the southern half bears southwestward. The topographic map shows the change in trend but fails to bring out the esker form which it presents.

From near Chili northeastward to the bend of Coldwater or Little Black Creek there is a sandy belt about 1 mile wide and 3 miles in length, which has a knob-and-basin topography. Its highest points stand about 60 feet above Little Black Creek. The topographic features as well as the sandy material suggest wind action, but bowlders were found embedded in the sand and on its surface, which seem to indicate that the features are only to a minor degree due to the wind. Glacial action seems to have been the main agency. The intricacy of this belt is brought out to a fair degree by the topographic map. South of this sandy belt from Chili eastward to the Genesee River is a gently undulating till tract, with knolls usually but 10 to 15 feet in height, while to the north the surface is even less undulatory and carries scarcely any sand. This sandy belt has about the same trend as the striæ of that vicinity, and meets the remainder of the moraine obliquely. It is in a nearly direct line of continuation of the Pinnacle Hills ridge of Rochester, but is separated from it by a gap about 4 miles in width, which is partly occupied by a later moraine. The presence of this moraine is thought to indicate that the Pinnacle Hills ridge was formed later than the Chili sand belt.

STRUCTURE OF THE DRIFT.

In the Barre moraine, as well as its associated spurs, eskers, etc., there is a large amount of gravel and sand. Indeed, till seems to predominate over assorted material only for a few miles east from Lockport. The ridges there as well as the plains are principally till. Farther east there seems to be considerable till in plane tracts, but the ridges are chiefly gravel. The most prominent ridges are usually thickly strewn with bowlders, but they are not so numerous on the low ridges and on plane tracts. Among the bowlders, which are largely of granitic rocks, there are not a few limestone slabs gathered from the immediate vicinity.

The drift is ordinarily so thick along the line of this moraine that wells are obtained without entering rock. There are, however, small areas around Shelby Center and Barre Center as well as farther east where the drift is very thin, so that the rock ledges are within reach of the plow.

RELATION TO LAKE WARREN.

The highest points on this moraine stand more than 100 feet below the level of the neighboring part of the beach of Lake Warren, while the lowest parts are several hundred feet below the level of that lake. On theoretical grounds the ice sheet appears to have terminated in that lake at the time the Barre moraine was forming. On this assumption its deposits are all water-laid. It seems remarkable that under these conditions assorted material, and especially coarse gravel beds, should form so prominent constituents of the drift. There being no line of rapid escape for the waters from the ice margin, it would seem natural for the fine material to be laid down with the coarse, though possibly there was sufficiently vigorous movement of water under the ice to cause much assorting of its deposits and removal of fine material.

ALBION MORAINE.

DISTRIBUTION.

The course of this moraine has been accurately traced only from Albion eastward to Rochester, but it has been crossed on the New York Central Railroad, directly south of Knowlesville, and appears from the contours of the Medina topographic sheet to come to the Erie Canal 1½ miles west of Knowlesville, and to be continued westward in a series of knolls on the borders of Oak Orchard Creek, 1 to 3 miles north of Medina. From the railway crossing south of Knowlesville to Albion the crest of the moraine is less than a mile south of the New York Central Railroad, and is followed by a "ridge road." The moraine is scarcely one-fourth of a mile in width, but presents a very definite ridge. It is cut through by Sandy Creek near the southeast edge of the city of Albion, but the gap is very narrow, and the ridge continues to the Albion Cemetery, 1½ miles east of the city, where it rises into greater prominence.

There are minor ridges and small knolls and also basins in Albion and eastward to the cemetery, extending out to a distance of nearly a mile north of the main ridge, but west from Albion such features are rare.

At Albion Cemetery there is a knoll standing nearly 100 feet above low ground on the south and 60 to 75 feet above the neighboring parts of the moraine. Toward the east the moraine continues with sharp ridges and

knolls as far as the west border of Murray Township, 2 miles. It is then vague for about a mile, but reappears on the brow of the Niagara escarpment near a schoolhouse. About one-fourth mile east of the schoolhouse a gap about one-fourth mile wide sets in, but this gap is bridged by a reef of bowlders. East of this gap for about 2 miles the ridge lies just south of an east-west road and is very sharp and narrow.

About $1\frac{1}{2}$ miles west of Holley the moraine makes a southward jog to Clarendon, and thence passes in a nearly east course into Monroe County. In this deflection it passes around an esker that lies between Holley and Clarendon.

The moraine becomes more complex on passing east from Clarendon, its ridges and knolls being scattered over a belt 1 to 2 miles wide, lying mainly south of the Erie Canal. The main ridge, however, is along the southern border, and is, as a rule, definite and nearly continuous. It passes through Lake View Cemetery, $1\frac{1}{2}$ miles south of Brockport. There are drift knolls and ridges in Brockport and eastward from there to Spencerport in sufficient number to give a morainic aspect to the surface.

From Adams Basin, 2 miles west of Spencerport, a morainic spur extends north nearly 2 miles, occupying a width of about a mile, but the moraine presents a definite east-west ridge opposite the south end of this spur, which passes about one-half mile south of Adams Basin and Spencerport. There are drift knolls around Spencerport and for a mile or more east and north, but the moraine takes a southeastward course into Gates Township, its crest passing just south of West Gates and crossing the main line of the New York Central Railroad a mile southwest of Gates. It continues south of east to the Genesee River in the south part of Rochester, upon crossing which it connects directly with the west end of the Pinnacle Hills ridge.

The Pinnacle Hills ridge is thought by Fairchild to be a marginal moraine, but to the writer it appears more like a spur extending back from the inner border of the moraine. A low till ridge, which leads from its western end southward toward Ridgeland, is thought to mark the continuation of the Albion moraine. As this lies beyond the field allotted for investigation, its course was not traced farther than Ridgeland. The relation of striæ to this ridge is discussed farther on (p. 709).

RANGE IN ALTITUDE.

The altitude of the crest of the moraine is only about 540 feet at the Erie Canal west of Knowlesville, while the altitude of knolls farther west in the northern part of the Medina quadrangle is from 540 to 550 feet. The altitude gradually increases eastward, the 600-foot contour being reached in the western part of Albion Township and the 620-foot contour 2 miles southwest of Albion. The cemetery hill east of Albion rises above the 680-foot contour, but neighboring portions of the crest are scarcely 640 feet, and it stands near the 640-foot contour for several miles to the east. About 3 miles southwest of Brockport the crest rises above the 660-foot contour, and immediately south of the village it passes the 680-foot contour. A knoll here appears, which rises above the 720-foot contour, but the general elevation for a mile is about 680 feet. Between Brockport and Spencerport the altitude decreases to about 600 feet, and from that village southeastward into Gates Township only the prominent knolls rise above that contour. At the crossing of the main line of the New York Central Railroad southwest of Gates it is barely 580 feet, and few points from there eastward to the Buffalo, Rochester and Pittsburg Railroad rise to this contour, while at the bluffs of the Genesee the altitude is only about 560 feet, and from the river southward to Ridgeland it is between 560 and 580 feet. The Pinnacle Hills ridge varies greatly in altitude, its northeastern end at Brighton being barely 500 feet, while the highest point rises above the 740-foot contour. Much of the crest stands above the 600-foot contour.

Between Albion and Brockport, where the crest of the moraine is highest, morainic knolls and ridges abound along the face of the Niagara escarpment down about to the level of the Erie Canal, 510 feet, but are rare north of the canal except in the spur near Adams Basin, where they extend about 2 miles north of the canal. The highest points on this spur are about 560 feet and the lowest about 460 feet.

TOPOGRAPHY.

The main ridge throughout much of its course has an abrupt outer border relief of 20 to 30 feet, and is more nearly continuous than any ridges in neighboring moraines. There are, aside from the large knolls which occasionally appear along the crest, numerous small knolls and gentle swells along the crest and on the slopes. The knolls and ridges which lie

north of the main ridge are ordinarily but 10 to 20 feet in height, and the ridging is far less conspicuous than in the main ridge.

The sharply ridged parts of this inner border are confined chiefly to the esker near Holley, the spur near Adams Basin, and the Pinnacle Hills ridge in Rochester.

The Holley esker sets in about a mile southwest of that village and extends southwestward to within one-half mile of Clarendon, its length being about $1\frac{1}{2}$ miles. It is a nearly continuous ridge, though it varies greatly in height, there being hummocks on it. One of these hummocks rises 40 feet above the adjacent parts of the ridge, while others rise 15 feet or more. The ridge is in places very sharp, in one place its width being only 30 or 40 yards and its height 20 to 30 feet. Along each side of the ridge gravelly knolls abound, which rise 10 to 20 feet above the marshy tract in which the esker lies. These knolls also extend around the southern end of the ridge, being numerous at Clarendon and for a short distance south and east of the village.

The spur near Adams Basin does not carry a definite esker ridge, but consists of irregular-shaped knolls, which are often grouped into small clusters. The intricacy of contours is only faintly portrayed on the topographic map (Pl. III).

The Pinnacle Hills ridge, which received the attention of many geologists attending the Rochester Meeting of the Association for Advancement of Science, in 1892, has since been described by Upham[1] and by Fairchild.[2] With a width of but one-eighth to one-half mile, including slopes, and a height of 50 to 240 feet, it constitutes a very conspicuous drift feature. It does not present the form of a typical esker, though it was put in this category by Upham. Its topography is more like that of a very sharp moraine, and the name kame-moraine given by Fairchild seems highly applicable. The following description of the topography is taken from Fairchild's paper just cited:

The Pinnacle Hills extend from the village of Brighton to the Genesee River, a distance of 4 miles, with a general direction of west 15° south. The belt of hills has a linear form with a distinct curvature of large radius, the convexity facing southward. The range, however, is not continuous or uniform, but consists of groups of

[1] Eskers near Rochester, N. Y., by Warren Upham: Proc. Rochester Acad. Science, Vol. II, 1893, pp. 181–200.

[2] The kame-moraine at Rochester, N. Y., by H. L. Fairchild: Am. Geologist, Vol. XVI, 1895, pp. 39–51; with map.

irregular hills and knolls, three main divisions being easily recognized. The first large group extends from Brighton to Monroe avenue. This group is subdivided by a deep cut, the western mass being known as Cobbs Hill, with a summit height of 663 feet above tide. The sag which was cut by Monroe avenue originally had an elevation of 560 feet. The second large group lies between Monroe avenue and a sag or depression one-fourth of a mile west of South Clinton street (Pinnacle avenue). This group is the most distinct and compact, and contains the highest point in the whole range, called the "Pinnacle," which name has been extended to cover the whole series of hills. The altitude of this summit is 749 feet, or about 240 feet above the surrounding plain. The third group may be regarded as including all the western part of the hill range, which is lower than the eastern part, much broader and less definite. This includes in succession, westwardly, the knolls east of South Goodman street; Highland Park, between Goodman street and South avenue; the "Warner tract," lying between South and Mount Hope avenues; Mount Hope Cemetery, lying west of Mount Hope avenue; and the low point running into a bend of the Genesee River. The highest points in this area are the knoll on which is built the memorial pavilion near the reservoir, 650 feet, and the summits in the cemetery, 650 to 670 feet.

The eastern portion of the range consists of a series of overlapping ridges or elongated mounds having their longest diameters parallel in general with the trend of the range. Only at the "Pinnacle" is the cross section a single ridge, and this part is better described as an elongated, irregular mound. The width of the belt at Cobbs Hill is but little less than one-half mile, and here the crests of the southern and northern series of ridges or mounds are but one-fourth mile apart. At South Goodman street the two series of ridges are one-eighth of a mile apart. The western third of the range, or the portion beyond South Goodman street, is very different, there being, instead of east-west ridges, a broader irregular aggregation of mounds with a larger number of inclosed basins.

The crest line is very irregular, nowhere level for any distance, and varying 100 to 180 feet in height between the groups of hills. The northern slopes of the range are irregular, with spurs, and hillocks and deep ravines, and over the eastern half of the range are usually as steep as the material will rest, 25° to 30°. The southern slopes are more smooth and uniform, commonly with gentle inclination to the southern plain into which they blend.

The irregularity of the hills is great in both longitudinal and transverse sections. The only feature of evident system is the linear arrangement of the series, taken as a whole.

A striking feature which has not been sufficiently noted is the frequent occurrence of "kettle holes" and basins. A better example of mound and basin topography might not be desired than is found in Mount Hope Cemetery. Beautiful examples of "kettle holes" are seen here; also in the Warner tract; also east of South Goodman street, and east of Cobbs Hill. The only ponds or swamps are found east of South Goodman street, where one pond occurs, lying at the base of the hills, and one large oval basin has been filled with peat to a depth of at least 6 feet.

There is a small ridged and knolly drift tract on the inner border of the moraine in the west part of Rochester to which Fairchild, in the paper just

cited, has applied the name "Lincoln Park kame area." It consists of a series of low gravel and sand knolls distributed in a belt $1\frac{1}{2}$ miles long from north to south and less than one-half mile wide. The largest are but 20 to 30 feet in height and from 200 yards to about one-fourth mile in length. These knolls are recognized by Fairchild to be inside the frontal moraine.

STRUCTURE OF THE DRIFT.

The main ridge of the Albion moraine apparently contains a much larger percentage of till than is found in the moraines outside of it. It is a clayey till, thickly set with small stones, and bears a close resemblance to the ordinary till of the plains to the west of Lake Erie. Its surface is liberally strewn with bowlders and so is the inner slope of the moraine.

The small knolls and ridges on the inner slope also contain much till, but the large knolls are in many instances composed chiefly of sand and gravel.

Fairchild has given a detailed description of several sections in the Pinnacle Hills ridge from which it appears that the north slope and crest carry a large amount of till, but the south slope and basal portion of the ridge are composed chiefly of gravel and sand. The dip of the beds is not westward, or lengthwise of the range of hills, nor is it from the crest toward each border, as is common in eskers. In general it is southward and east of south, or across the trend line. The southward dip is found to be most pronounced in the gravels upon the north side of the range, and there is an approach to horizontality in passing toward the south flank. There are many local exceptions, but these have seemed to Fairchild to be in large part due to disturbances by ice thrust, to which should probably be added disturbances from settling of the beds.

Large blocks of Lockport (Niagara) limestone abound on the surface and in the till of the Pinnacle Hills ridge. Their altitude reaches more than 200 feet above the outcrops of this limestone in the districts to the north, and yet they seem to be derived from that district within a distance of 5 miles.

In the esker near Holley there are two gravel pits near its northeast end. The bedding is imperfect in the surface portion to a depth of several feet, there being earthy or clayey material commingled with sand and gravel. Below this depth the bedding is distinct, but it is variable, for the beds

arch and dip at various angles. They, however, show a tendency to slope with the surface from the crest toward each side of the ridge. A surprising feature in these gravel pits is the very large percentage of Medina sandstone fragments. By actual count they constitute about 90 per cent of the pebbles. The sand also must contain a large amount of rock fragments of the same formation, for it has the pink tinge characteristic of the sandstone and shales.

The till of this moraine occasionally presents a pink tinge because of the presence of the Medina shales, but ordinarily it has a blue cast and the coarse fragments seem to consist more largely of limestone than of sandstone. The granitic and other crystalline rocks of distant derivation do not constitute a prominent part of the till, but are very abundant on the surface.

RELATION TO LAKE WARREN.

Until this moraine has been traced farther east its relations to Lake Warren can only be conjectured. It was probably formed near the close of the existence of that lake, for the waters must have fallen to a lower level as soon as the ice sheet uncovered the Mohawk outlet. Possibly the outlet was opened and the lake level lowered before the moraine was formed.

INNER BORDER PHENOMENA.

Between the Albion moraine and Lake Ontario there is a plain sloping gradually toward the lake, as may be seen by Pl. III. It is traversed by the Iroquois beach, which lies 1 to 4 miles north from the inner border of the moraine, from the Genesee westward to Oak Orchard Creek. Above the level of this beach drift swells are not uncommon, but below it they are very rare. There are, however, just west of the mouth of the Genesee, a few small drumlins, standing only 50 to 75 feet above the level of Lake Ontario, or more than 100 feet below the level of the Iroquois beach.

The drift is usually thin throughout this plain, a depth of 50 feet being rare. It has been noted by Gilbert[1] that the divides between the drainage lines usually carry a smaller amount of drift than the sags through which the streams have their courses. This, as Gilbert announced, is a matter of some significance, in that it shows that the drainage is not controlled by ridges of drift, but instead by furrows in the rock. He considers these furrows immense glacial groves, as indicated more fully below (p. 709).

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[1] Bull. Geol. Soc. America, Vol. X, 1899, pp. 126–129.

In addition to the furrowing just mentioned, Gilbert has discovered an interesting dislocation of the Medina shale at Thirtymile Point, which he attributes to glacial thrust.[1]

GLACIAL STRIÆ.

Numerous observations of glacial striæ have been made by the writer and by others on the Corniferous escarpment from Batavia westward, and on the Niagara escarpment from Rochester westward to the Niagara River, all of which have a bearing west of south. They vary, however, from S. 5° W. to S. 60° W. A similar variation in trend is found in the drumlins which appear between these escarpments and which are thought to indicate the direction of ice movement.

On the uplands south of the Corniferous escarpment two observations of striæ were made in western Wyoming County which bear east of south, one being S. 20° E., and the other S. 30° to 35° E. They are near the point of connection of the Gowanda moraine with the interlobate belt, the one with bearing S. 20° E., being 1½ miles west of North Sheldon, while the one with bearing S. 30° E., is 2 miles southwest of Sheldon Center. The diversity in the bearing of the striæ in the low country lying between Lakes Ontario and Erie and of those on the uplands to the south, may simply indicate a difference in the direction of movement of ice in the axial and the peripheral portions. A southwestward axial movement is to be inferred from the fact that in the late stage of glaciation the ice sheet moved from the Lake Ontario into the Lake Erie basin; but the margin need not partake of this movement, for in crowding against the uplands on the south of these basins it would be liable to move in a southeastward direction. There is a possibility, however, that the striæ on the uplands of Wyoming County were formed at a much earlier date than those on lower land to the north and northwest, and that at the time they were formed the ice sheet had a general southeastward movement across the lake basins, its thickness being so great that the basins then had little influence upon its course.

Irving P. Bishop, of the New York survey, has brought to notice several instances of striation on the bed and bluffs of Niagara River near Buffalo, which show that the channel had nearly its present depth prior to the close of the Glacial epoch.[2] A photograph of a striated ledge at the

[1] Loc. cit., pp. 131–134.

[2] Fifteenth Ann. Rept. New York Geol. Survey, 1895, pp. 325, 326, 392

Lehigh coal sheds, about 6 miles east of Buffalo, accompanies Bishop's report. Several acres were stripped of drift to expose the rock, which was used as a floor for the sheds. The surface, though in places slightly undulating, is well polished, and sharp grooves are numerous.

Gilbert's recent studies of glacial sculpture in western New York[1] have brought to light numerous exposures of glaciated ledges, about fifteen of which are along the brow and face of the Niagara escarpment between Lockport and the Niagara River. Evidence has also been found that the shales to the north have been furrowed by the ice on a grand scale, the furrows being in some cases at least 40 feet in depth and hundreds of feet in width. These great furrows have a southwestward trend or bearing similar to that of the striæ on the hard rocks of the region.

Fairchild has found, near Rochester, two sets of striæ, an older, main set with a bearing S. 40° to 60° W., and a later, light striation, hardly more than a polishing, with a bearing S. 5° to 15° W. on the west side of the Genesee, while they are slightly east of south on the east side of the river. He considers the latter set of similar age to the Albion moraine and calls attention to the fact that their direction is about perpendicular to the arc of the moraine. It is not certain, however, that such a phase of striation might not accompany the production of a spur since the ice is liable to be to some extent lobed on each side of a spur and to have more or less movement toward it. The movement in connection with the Pinnacle Hills ridge would naturally be stronger toward the north side than toward the south, since the main body of ice stood on that side, and probably had a movement southward as well as westward.

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[1] Bull. Geol. Soc. America, Vol. X, 1899, pp. 121–130.

CHAPTER XIV.

THE GLACIAL LAKE MAUMEE.

INTRODUCTORY.

Lake Maumee is the first and highest of a series of large, definitely outlined glacial lakes which occupied the Huron-Erie basin. This lake, as noted in the discussion of the Fort Wayne and Defiance moraines, was preceded by a few small, disconnected lakes which lay between the ice margin and the divide south of Lake Erie, and which found outlets at several points across the divide at levels somewhat higher than the Fort Wayne outlet.

Lake Maumee was limited on the south and west by a land barrier, but its limits on the north and east were determined by the retreating ice sheet. The Defiance moraine marks the position which the ice sheet held during a large part of the lake's existence (see Pl. XX). With the melting back of the ice the lake expanded its area to the limits shown in Pl. XXI. The outlet past Fort Wayne was the lowest available point on the bordering rim at the beginning of the lake's existence, but later, the ice having melted away from another point equally low near Imlay, Mich., the lake for a brief time seems to have had two outlets.

With the further withdrawal of the ice a still lower outlet became available, and with the change of outlet and lowering of level this lake's history closed and that of its successor, Lake Whittlesey, had its beginning. The latter in turn was succeeded by a lake with still different outlet and lower level, and these changes were continued, as will be described in the discussion which follows.

Lake Maumee will here include the uppermost two beaches of the Huron-Erie basin with the two outlets, the Fort Wayne and the Imlay, for it now appears probable that the former outlet continued in operation after the latter was opened. The beaches will be called the first Maumee and the second Maumee, these names being more readily understood than any other of the several names which have been applied. The name Lake

MICHIGAN

1 MASON
2 LAKE
3 OSCEOLA
4 CLARE
5 GLADWIN
6 ARENAC
7 HURON
8 BAY
9 MIDLAND
10 ISABELLA
11 MECOSTA
12 NEWAYGO
13 OCEANA
14 MUSKEGON
15 MONTCALM
16 GRATIOT
17 SAGINAW
18 TUSCOLA
19 SANILAC
20 ST. CLAIR
21 LAPEER
22 GENESEE
23 SHIAWASSEE
24 CLINTON
25 IONIA
26 KENT
27 OTTAWA
28 ALLEGAN
29 BARRY
30 EATON
31 INGHAM
32 LIVINGSTON
33 OAKLAND
34 MACOMB
35 WAYNE
36 WASHTENAW
37 JACKSON
38 CALHOUN
39 KALAMAZOO
40 VAN BUREN
41 BERRIEN
42 CASS
43 ST. JOSEPH
44 BRANCH
45 HILLSDALE
46 LENAWEE
47 MONROE

INDIANA

1 LAPORTE
2 ST. JOSEPH
3 ELKHART
4 LAGRANGE
5 STEUBEN
6 DEKALB
7 NOBLE
8 KOSCIUSKO
9 MARSHALL
10 STARKE
11 PULASKI
12 FULTON
13 WHITLEY
14 ALLEN
15 ADAMS
16 WELLS
17 HUNTINGTON
18 WABASH
19 MIAMI
20 CASS
21 CARROLL
22 HOWARD
23 GRANT
24 BLACKFORD
25 JAY
26 RANDOLPH
27 DELAWARE
28 MADISON
29 TIPTON
30 CLINTON
31 BOONE
32 HAMILTON
33 HENRY
34 WAYNE
35 HANCOCK
36 MARION
37 HENDRICKS
38 MORGAN
39 JOHNSON
40 SHELBY
41 RUSH
42 FAYETTE
43 UNION
44 FRANKLIN
45 DECATUR
46 BARTHOLOMEW
47 BROWN
48 JACKSON
49 JENNINGS
50 RIPLEY
51 DEARBORN
52 SWITZERLAND
53 JEFFERSON
54 SCOTT
55 WASHINGTON
56 CLARK
57 FLOYD
58 HARRISON

OHIO

1 WILLIAMS
2 FULTON
3 LUCAS
4 OTTAWA
5 LAKE
6 ASHTABULA
7 TRUMBULL
8 GEAUGA
9 CUYAHOGA
10 LORAIN
11 ERIE
12 SANDUSKY
13 WOOD
14 HENRY
15 DEFIANCE
16 PAULDING
17 PUTNAM
18 HANCOCK
19 SENECA
20 HURON
21 MEDINA
22 SUMMIT
23 PORTAGE
24 MAHONING
25 COLUMBIANA
26 STARK
27 WAYNE
28 ASHLAND
29 RICHLAND
30 CRAWFORD
31 WYANDOT
32 ALLEN
33 VAN WERT
34 MERCER
35 AUGLAIZE
36 HARDIN
37 MARION
38 MORROW
39 KNOX
40 HOLMES
41 COSHOCTON
42 TUSCARAWAS
43 CARROLL
44 HARRISON
45 JEFFERSON
46 BELMONT
47 GUERNSEY
48 MUSKINGUM
49 LICKING
50 DELAWARE
51 UNION
52 LOGAN
53 SHELBY
54 DARKE
55 MIAMI
56 CHAMPAIGN
57 CLARK
58 MADISON
59 FRANKLIN
60 PICKAWAY
61 FAIRFIELD
62 PERRY
63 MORGAN
64 NOBLE
65 MONROE
66 WASHINGTON
67 ATHENS
68 HOCKING
69 VINTON
70 ROSS
71 FAYETTE
72 GREENE
73 MONTGOMERY
74 PREBLE
75 BUTLER
76 WARREN
77 CLINTON
78 HIGHLAND
79 PIKE
80 JACKSON
81 MEIGS
82 GALLIA
83 LAWRENCE
84 SCIOTO
85 ADAMS
86 BROWN
87 CLERMONT
88 HAMILTON

KENTUCKY

1 BOONE
2 KENTON
3 CAMPBELL
4 GREENUP
5 LEWIS
6 MASON
7 BRACKEN
8 PENDLETON
9 GRANT
10 GALLATIN
11 CARROLL
12 TRIMBLE
13 OLDHAM
14 HENRY
15 OWEN
16 HARRISON
17 ROBERTSON
18 FLEMING
19 CARTER
20 BOYD
21 LAWRENCE
22 ELLIOTT
23 ROWAN
24 BATH
25 NICHOLAS
26 BOURBON
27 SCOTT
28 FRANKLIN
29 SHELBY
30 JEFFERSON
31 BULLITT
32 SPENCER
33 ANDERSON
34 WOODFORD
35 FAYETTE
36 CLARK
37 MONTGOMERY

NEW YORK

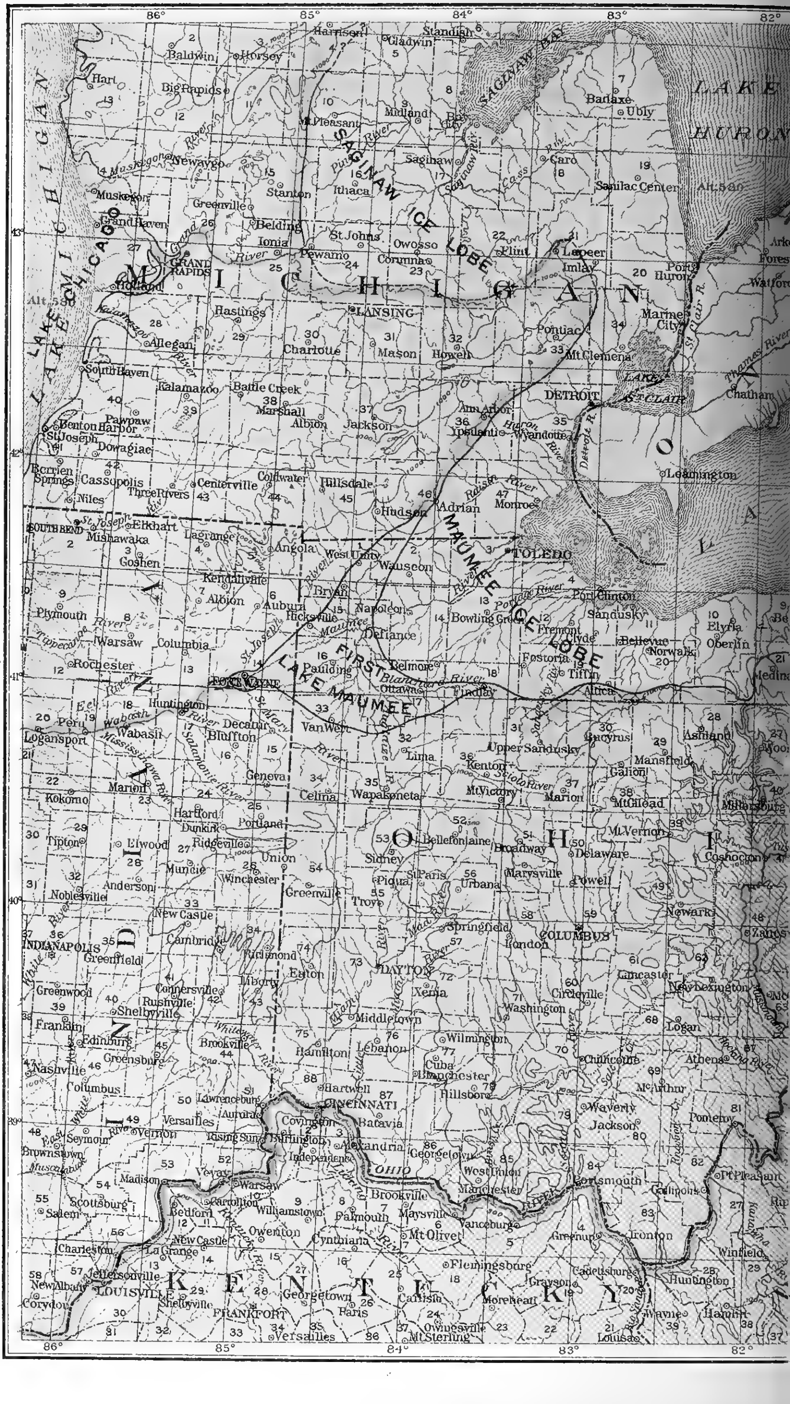
1 JEFFERSON
2 LEWIS
3 ONEIDA
4 OSWEGO
5 CAYUGA
6 WAYNE
7 MONROE
8 ORLEANS
9 NIAGARA
10 ERIE
11 GENESEE
12 WYOMING
13 LIVINGSTON
14 ONTARIO
15 YATES
16 SENECA
17 ONONDAGA
18 MADISON
19 CHENANGO
20 CORTLAND
21 TOMPKINS
22 SCHUYLER
23 BROOME
24 TIOGA
25 CHEMUNG
26 STEUBEN
27 ALLEGANY
28 CATTARAUGUS
29 CHAUTAUQUA

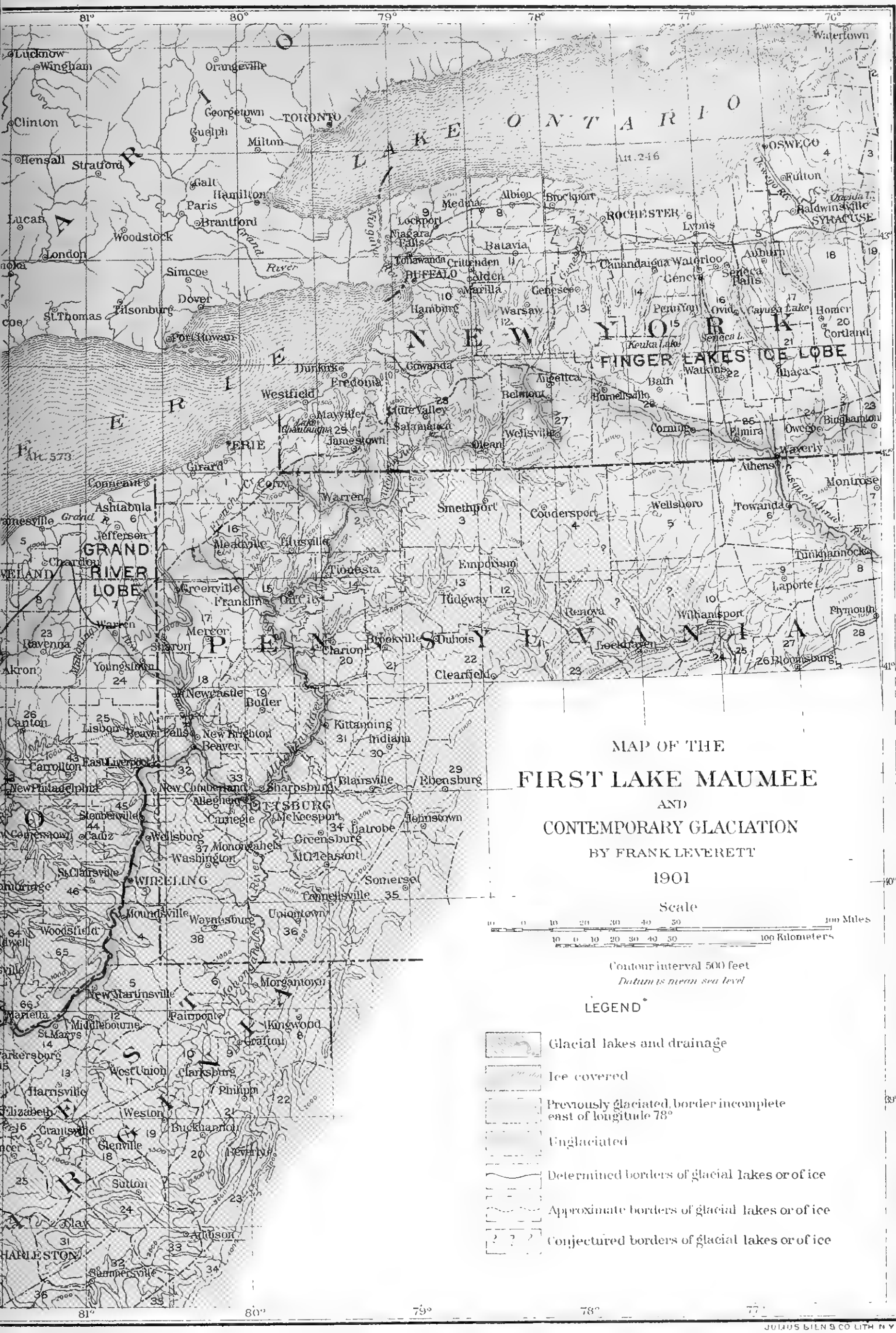
PENNSYLVANIA

1 ERIE
2 WARREN
3 MC KEAN
4 POTTER
5 TIOGA
6 BRADFORD
7 SUSQUEHANNA
8 WYOMING
9 SULLIVAN
10 LYCOMING
11 CLINTON
12 CAMERON
13 ELK
14 FOREST
15 VENANGO
16 CRAWFORD
17 MERCER
18 LAWRENCE
19 BUTLER
20 CLARION
21 JEFFERSON
22 CLEARFIELD
23 CENTER
24 UNION
25 NORTHUMBERLAND
26 MONTOUR
27 COLUMBIA
28 LUZERNE
29 CAMBRIA
30 INDIANA
31 ARMSTRONG
32 BEAVER
33 ALLEGHENY
34 WESTMORELAND
35 SOMERSET
36 FAYETTE
37 WASHINGTON
38 GREENE

WEST VIRGINIA

1 HANCOCK
2 BROOKE
3 OHIO
4 MARSHALL
5 WETZEL
6 MONONGALIA
7 MARION
8 PRESTON
9 TAYLOR
10 HARRISON
11 DODDRIDGE
12 TYLER
13 RITCHIE
14 PLEASANTS
15 WOOD
16 WIRT
17 CALHOUN
18 GILMER
19 LEWIS
20 UPSHUR
21 BARBOUR
22 TUCKER
23 RANDOLPH
24 BRAXTON
25 ROANE
26 JACKSON
27 MASON
28 CABELL
29 PUTNAM
30 KANAWHA
31 CLAY
32 NICHOLAS
33 WEBSTER
34 POCAHONTAS
35 GREENBRIER
36 FAYETTE
37 BOONE
38 LINCOLN
39 WAYNE





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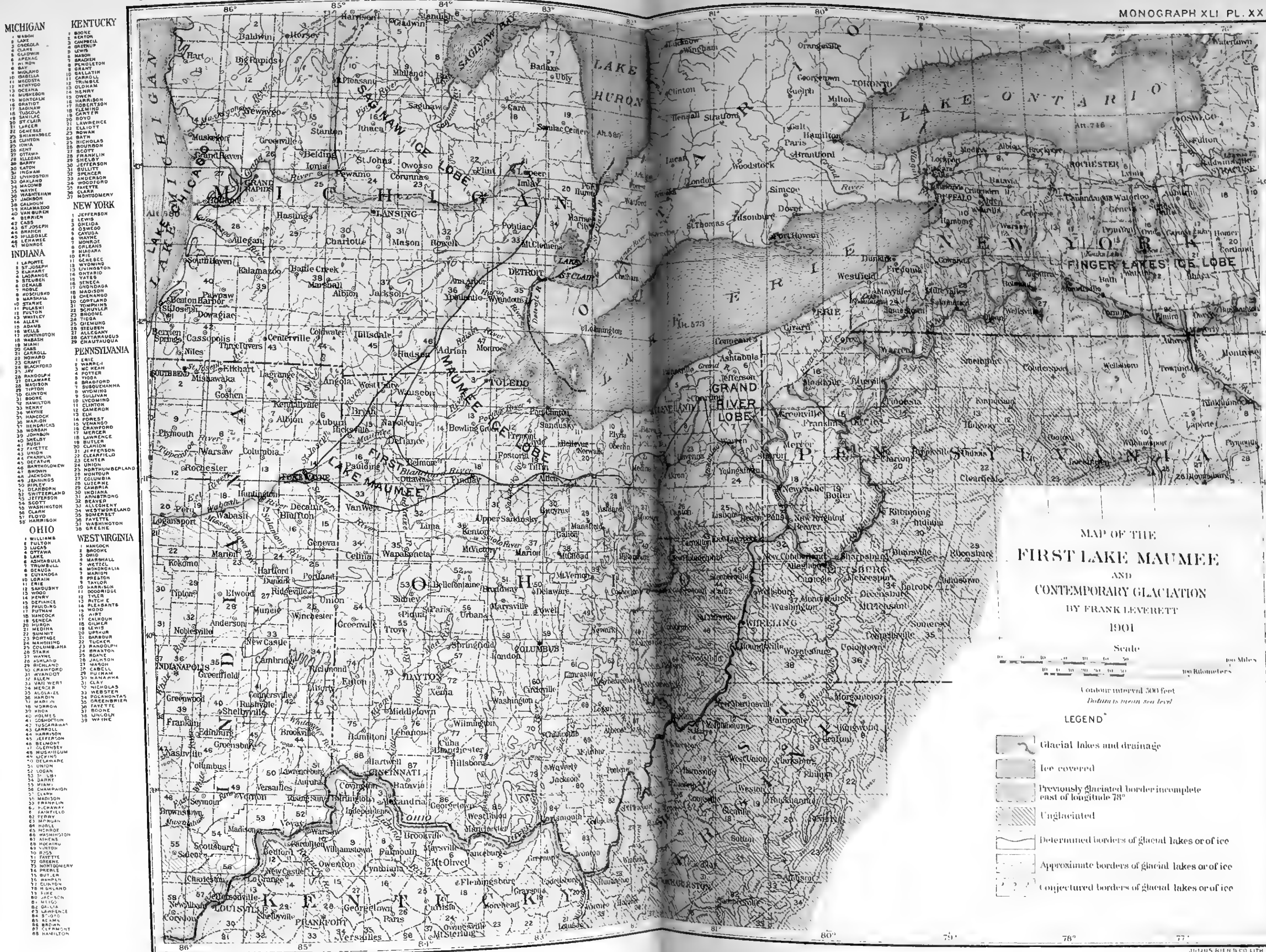
MICHIGAN
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4 CLARE
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40 VAN BUREN
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INDIANA
1 LAPORTE
2 ST. JOSEPH
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5 STEUBEN
6 DEKALB
7 NOBLE
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9 MARSHALL
10 STARKE
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12 FULTON
13 WHITLEY
14 ALLEN
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18 WABASH
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6 BRADFORD
7 SUSQUEHANNA
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11 CLINTON
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34 POCAHONTAS
35 GREENBRIER
36 FAYETTE
37 BOONE
38 LINCOLN
39 WAYNE
LAKE HURON
SAGINAW BAY
SAGINAW ICE LOBE
LAKE MICHIGAN
CHICAGO
MICHIGAN
LAKE ONTARIO
ONTARIO
LAKE ERIE
NEW YORK
FINGER LAKES ICE LOBE
GRAND RIVER LOBE
MAUMEE ICE LOBE
FIRST LAKE MAUMEE
INDIANA
OHIO
PENNSYLVANIA
KENTUCKY
VIRGINIA
MAP OF THE
FIRST LAKE MAUMEE
AND
CONTEMPORARY GLACIATION
BY FRANK LEVERETT
1901
Scale
100 Miles
100 Kilometers
Contour interval 500 feet
Datum is mean sea level
LEGEND
Glacial lakes and drainage
Ice covered
Previously glaciated border incomplete east of longitude 78°
Unglaciated
Determined borders of glacial lakes or of ice
Approximate borders of glacial lakes or of ice
Conjectured borders of glacial lakes or of ice
JULIUS BIEN & CO. LITH. N.Y.

Maumee was first applied in 1888 by C. R. Dryer, of the Indiana Geological Survey, in an official report on the "Geology of Allen County, Indiana," which includes a discussion of the western ends of the beaches and the Fort Wayne outlet.[1]

FORT WAYNE OUTLET OR WABASH-ERIE CHANNEL.

The former extension of lake waters to Fort Wayne was known as long ago as 1840, for Bela Hubbard makes reference to such an extension in a State report published that year.[2] It is probable, also, that the outlet to the Wabash was recognized at that time, but the outlet seems to have received its first careful examination by Gilbert about thirty years later, during his investigation of the Maumee Valley for the Ohio Geological Survey. He called attention to it in 1871[3] and again in his official report published in 1873.[4] The outlet was very briefly described in each publication and no name was applied to it. The first name which it appears to have received in print was that applied by Dryer in his report above mentioned, where it is called the Wabash-Erie channel. This name, however, seems not to have met with such favor as the name Fort Wayne outlet, which, though later introduced into the literature, has for several years been in use among geologists, and is now quite common in print. The term "Fort Wayne outlet" has the advantage also of being in harmony with the nomenclature adopted for the other (Imlay) outlet, both being from towns situated near the points where the outlets led away from the old lake, and both being termed outlets.

As indicated by Gilbert, the lake which formed the upper Maumee beach discharged southwestward into the Wabash River. The outlet begins about 2 miles west of New Haven, where the north and south shores cease converging and turn westward in parallel courses to form the bluffs of the stream. On reaching the Wabash the outlet has a length of fully 30 miles, but the enlargement due to the accession of the lake waters extends down the Wabash many miles farther. The width ranges from 1 mile up to

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[1] Sixteenth Ann. Rept. Geol. Survey Indiana, 1888, pp. 107–126.

[2] Third Ann. Rept. of Dr. Douglas Houghton, pp. 102–111. Published as house document No. 8, Detroit, 1840.

[3] On certain glacial and postglacial phenomena of the Maumee Valley, by G. K. Gilbert: Am. Jour. Sci., 3d series, Vol. I, 1871, pp. 339–345; see also a brief notice in Rept. Geol. Survey Ohio, 1870, Columbus, 1871, p. 488.

[4] Report on the surface geology of the Maumee Valley, etc. Geology of Ohio, Vol. I, 1873, pp. 550–551.

nearly 3 miles, the least width being in the city of Fort Wayne, where it passes through the Fort Wayne moraine, and the greatest width, 2 to 5 miles, being west of the city. The bluffs range in height from 15 or 20 feet up to about 75 feet, the highest part of the bluffs being near Aboit, at the place where the outlet cuts through the Wabash moraine. The bluffs in Fort Wayne, where the outlet crosses the Fort Wayne moraine, are scarcely 50 feet in height.

The bed of the outlet in Fort Wayne stands about 755 feet above tide, or 182 feet above Lake Erie, and the head near New Haven seems to be but a foot or two higher. From Fort Wayne to Lewis's ford, 3 miles east of Huntington, there appears to be a fall of but 11 feet, though the distance is nearly 25 miles. At this ford a ledge of limestone forms a barrier which was influential in causing the low rate of fall. Between this ledge and the junction with the Wabash River there is a fall of 45 feet in the present drainage line, Little River, and the lake outlet probably had nearly that amount of fall, for Little River has done scarcely any cutting in the bed of the outlet.

The bluffs of the outlet are abrupt throughout the entire distance from the head to its junction with the Wabash and far down the Wabash Valley, showing clearly the work of a vigorous stream. Parts of the bed are strewn with bowlders and cobblestones, also indicating an old scourway. The northwest part of the city of Fort Wayne stands on such a stony part of the bed. Between Fort Wayne and the ledge at Lewis's ford the bed is occupied by an extensive growth of peaty material, beneath which there is fine sand. This part had apparently been scoured out somewhat below its present level during the most vigorous stage of the excavation and was then filled in as the strength of the flow declined.

The outlet is also partially filled near its head by a delta of sand formed at the mouth of Sixmile Creek. Dryer estimates the average height of this delta to be about 10 feet above adjacent parts of the lake bottom,[1] and considers it the product of a stream that has passed from the St. Marys River Valley northward through the Sixmile Creek channel. This stream is reported to be still operative at exceptionally high stages of water in St. Marys River, though the main current passes around by Fort Wayne to the head of the Maumee River.

[1] Sixteenth Ann. Rept. Geol. Survey Indiana, 1888, p. 113.

SIXMILE CREEK CHANNEL.

This channel, which was brought to notice by Dryer,[1] has been discussed in connection with the Fort Wayne moraine, its course being southward from New Haven to the St. Marys River, through the Fort Wayne moraine, and thence westward to the Fort Wayne outlet. It is much smaller than the Fort Wayne outlet, being only about one-fourth mile in width. Although its bottom has a level 40 to 60 feet below neighboring parts of the moraine, its immediate banks are scarcely more than 15 feet in height. The channel is now drained northward by Sixmile Creek from within 2 miles of St. Marys River; but it seems to have been opened, or at least utilized, by waters of Lake Maumee discharging southward. The beach south of the lake turns up this channel on each side just as the north and south beaches turn westward into the Fort Wayne outlet. Furthermore, the recurved portion on the east side of Sixmile channel has been opened for gravel, and its bedding shows that it was formed by a southward-flowing stream. This line of discharge for Lake Maumee found its continuation down the St. Marys Valley but a short distance, for it left the river and passed directly west to join the Fort Wayne outlet about 6 miles southwest of Fort Wayne. The course is plainly marked by a channel about the same size as that along Sixmile Creek.

This channel was probably utilized only during the highest stage of Lake Maumee, for its summit is apparently a little higher than the second beach. The deposit of sand found near the north end of the channel may, as suggested by Dryer, represent, in part at least, the delta of the St. Marys River, formed after the lake level had become lower.

IMLAY OUTLET.

The headward part of the Imlay outlet, as described by Taylor,[2] is only about one-third of a mile wide at its narrowest place, averaging somewhat less than half a mile in width, and "does not give evidence of a very rapid or powerfully flowing current, if the sediments remaining on its bottom are taken as an indication, for it is floored mainly by sandy beds of gravel and not by bowlders and cobble." These gravel beds are found chiefly along the borders of the valley and stand 6 to 15 feet above the swamp which

[1] Sixteenth Ann. Rept. Geol. Survey Indiana, 1888, p. 112.
[2] Bull. Geol. Soc. America, Vol. VIII, 1897, pp. 37–39.

occupies its axis. In this narrow portion, which extends through parts of Goodland, Burnside, and North Branch townships, in Lapeer County, the banks are steep, as is also the west bank southward through Imlay Township. But below the village of North Branch the width is seldom less than a mile, and there are fewer places where the bordering bank is sufficiently steep to suggest cutting by the current.

Taylor argued in his paper that the narrowness of the Imlay outlet, as compared with that at Fort Wayne, seems to show that the former never carried the whole discharge from Lake Maumee, but that the Fort Wayne outlet also probably continued active. In a recent letter, however, he points out that a newly found fragment of the beach at the southwest corner of section 3 of Goodland Township overlooks the col and stands 20 to 25 feet above it. From this fact he suggests that the capacity of the narrow part of the outlet may have been largely compensated by the rather unusual depth of the water passing through it, and that there may have been after all little, if any, water left to flow out past Fort Wayne. The fact that the lower reaches of the Imlay outlet, as lately seen in Clinton and western Shiawassee counties, have an average width of a mile, thus comparing favorably with the width of the Fort Wayne outlet, gives some added strength to this view. Still, so far as could be made out from the faint features of the second beach near the head of the Fort Wayne outlet, it seems probable that this outlet did, in fact, continue to carry off some part of the discharge after the Imlay outlet had opened.

MAUMEE BEACHES, FROM THE FORT WAYNE TO THE IMLAY OUTLET.

Before a discussion of these beaches is begun a few explanatory statements seem necessary concerning the difficulty of discriminating between the first and second beaches. The strength of neither beach is great, except in places favorable for strong wave action. Where the lake plain inside of a beach slopes at the rate of 15 or 20 feet to the mile a well-defined ridge of wave-washed material or a cut bank may be expected, but where it becomes reduced to 10 feet or less per mile it can with difficulty be discerned, even though the surface, as stated by Gilbert, is remarkably adapted to receive the impress of the waves. In the case of the Maumee beaches conditions of slope are in places favorable for the strong development of both beaches, in places for but one, and in places for neither. As

MICHIGAN
1 MASON
2 LAKE
3 OSCEOLA
4 CLARE
5 GLADWIN
6 ARENAC
7 HURON
8 BAY
9 MIDLAND
10 ISABELLA
11 MECOSTA
12 NEWAYGO
13 OCEANA
14 MUSKEGON
15 MONTCALM
16 GRATIOT
17 SAGINAW
18 TUSCOLA
19 SANILAC
20 ST CLAIR
21 LAPEER
22 GENESEE
23 SHIAWASSEE
24 CLINTON
25 IONIA
26 KENT
27 OTTAWA
28 ALLEGAN
29 BARRY
30 EATON
31 INGHAM
32 LIVINGSTON
33 OAKLAND
34 MACOMB
35 WAYNE
36 WASHTENAW
37 JACKSON
38 CALHOUN
39 KALAMAZOO
40 VAN BUREN
41 BERRIEN
42 CASS
43 ST.JOSEPH
44 BRANCH
45 HILLSDALE
46 LENAWEE
47 MONROE

INDIANA
1 LAPORTE
2 ST.JOSEPH
3 ELKHART
4 LAGRANGE
5 STEUBEN
6 DEKALB
7 NOBLE
8 KOSCIUSKO
9 MARSHALL
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12 FULTON
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32 ALLEN
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35 AUGLAIZE
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NEW YORK
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22 SCHUYLER
23 BROOME
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26 STEUBEN
27 ALLEGANY
28 CATTARAUGUS
29 CHAUTAUQUA

PENNSYLVANIA
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2 WARREN
[illegible] MC KEAN
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7 SUSQUEHANNA
8 WYOMING
[illegible] SULLIVAN
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11 CLINTON
12 CAMERON
13 ELK
14 FOREST
15 VENANGO
16 CRAWFORD
17 MERCER
18 LAWRENCE
[illegible] BUTLER
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36 FAYETTE
37 WASHINGTON
38 GREENE

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8 PRESTON
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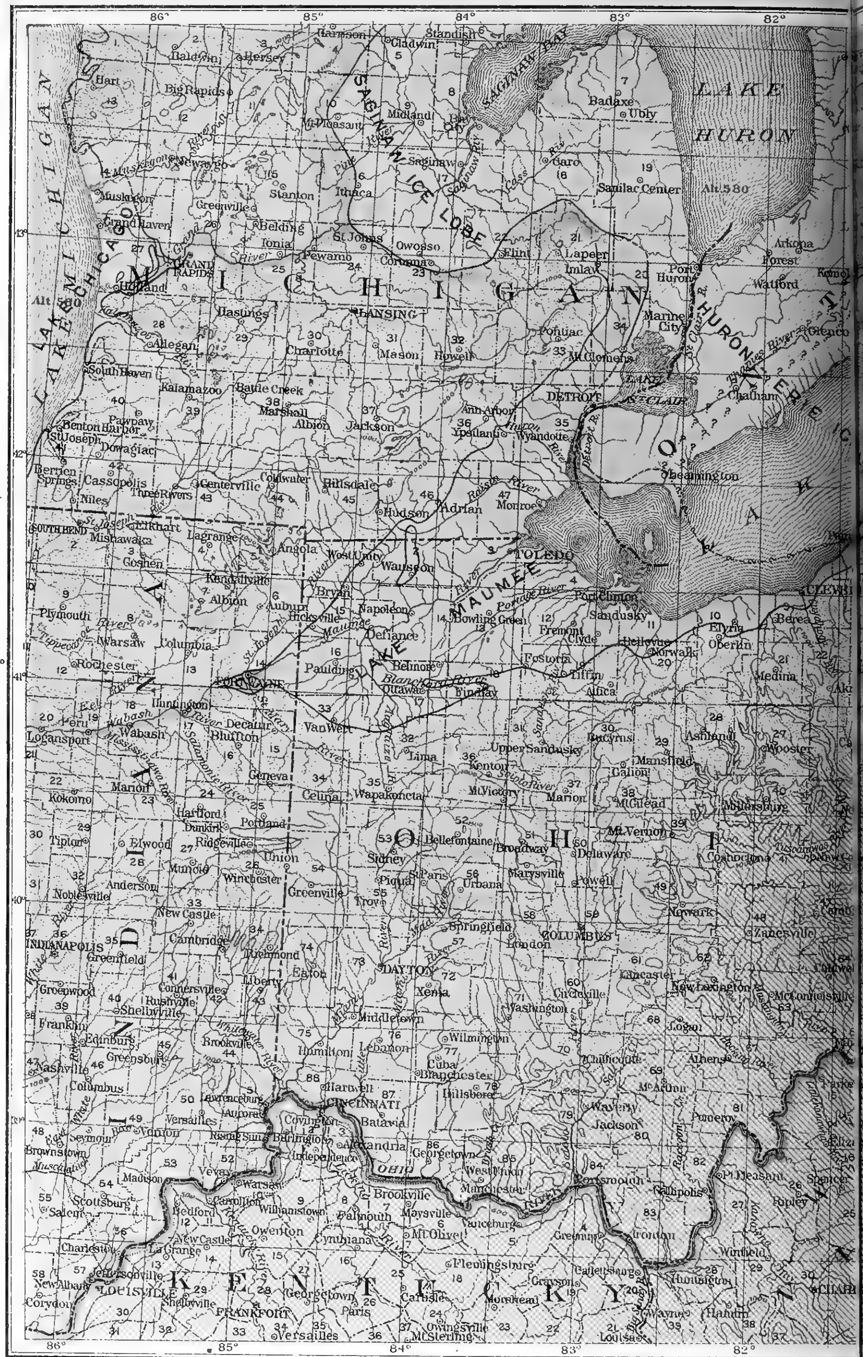
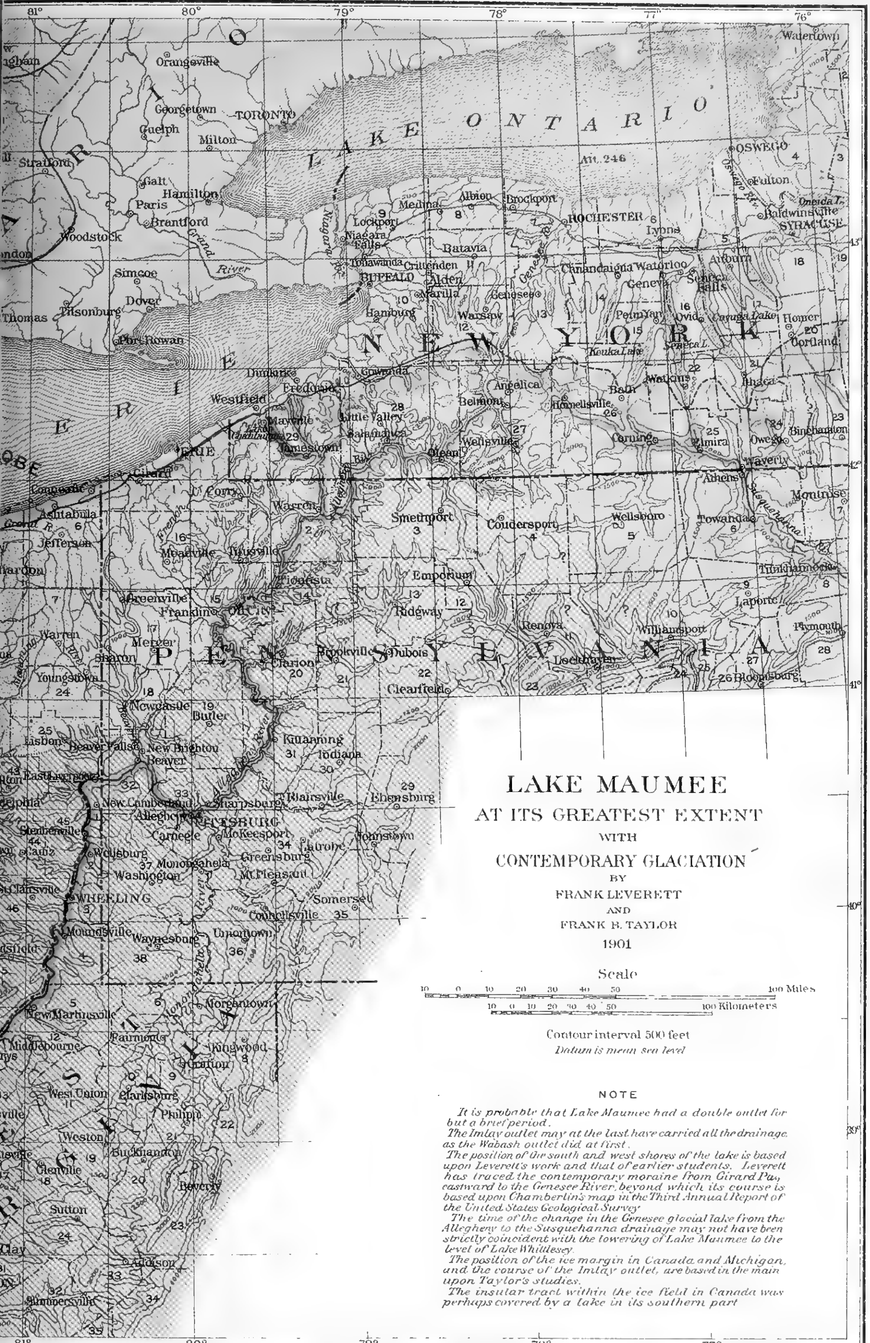
37 BOONE
38 LINCOLN
39 WAYNE





LAKE MAUMEE

AT ITS GREATEST EXTENT

WITH

CONTEMPORARY GLACIATION

BY

FRANK LEVERETT

AND

FRANK B. TAYLOR

1901

Scale

10 0 10 20 30 40 50 100 Miles

10 0 10 20 30 40 50 100 Kilometers

Contour interval 500 feet

Datum is mean sea level

LEGEND

Glacial lakes and drainage

Ice covered

Previously glaciated, border incomplete east of longitude 78°

Unglaciated

Determined borders of glacial lakes or of ice

Approximate borders of glacial lakes or of ice

? ? ?

Conjectured borders of glacial lakes or of ice

NOTE

It is probable that Lake Maumee had a double outlet for but a brief period.

The Imlay outlet may at the last have carried all the drainage as the Wabash outlet did at first.

The position of the south and west shores of the lake is based upon Leverett's work and that of earlier students. Leverett has traced the contemporary moraine from Girard Pa., eastward to the Genesee River, beyond which its course is based upon Chamberlin's map in the Third Annual Report of the United States Geological Survey

The time of the change in the Genesee glacial lake from the Allegheny to the Susquehanna drainage may not have been strictly coincident with the lowering of Lake Maumee to the level of Lake Whittlesey.

The position of the ice margin in Canada and Michigan, and the course of the Imlay outlet, are based in the main upon Taylor's studies.

The insular tract within the ice field in Canada was perhaps covered by a lake in its southern part

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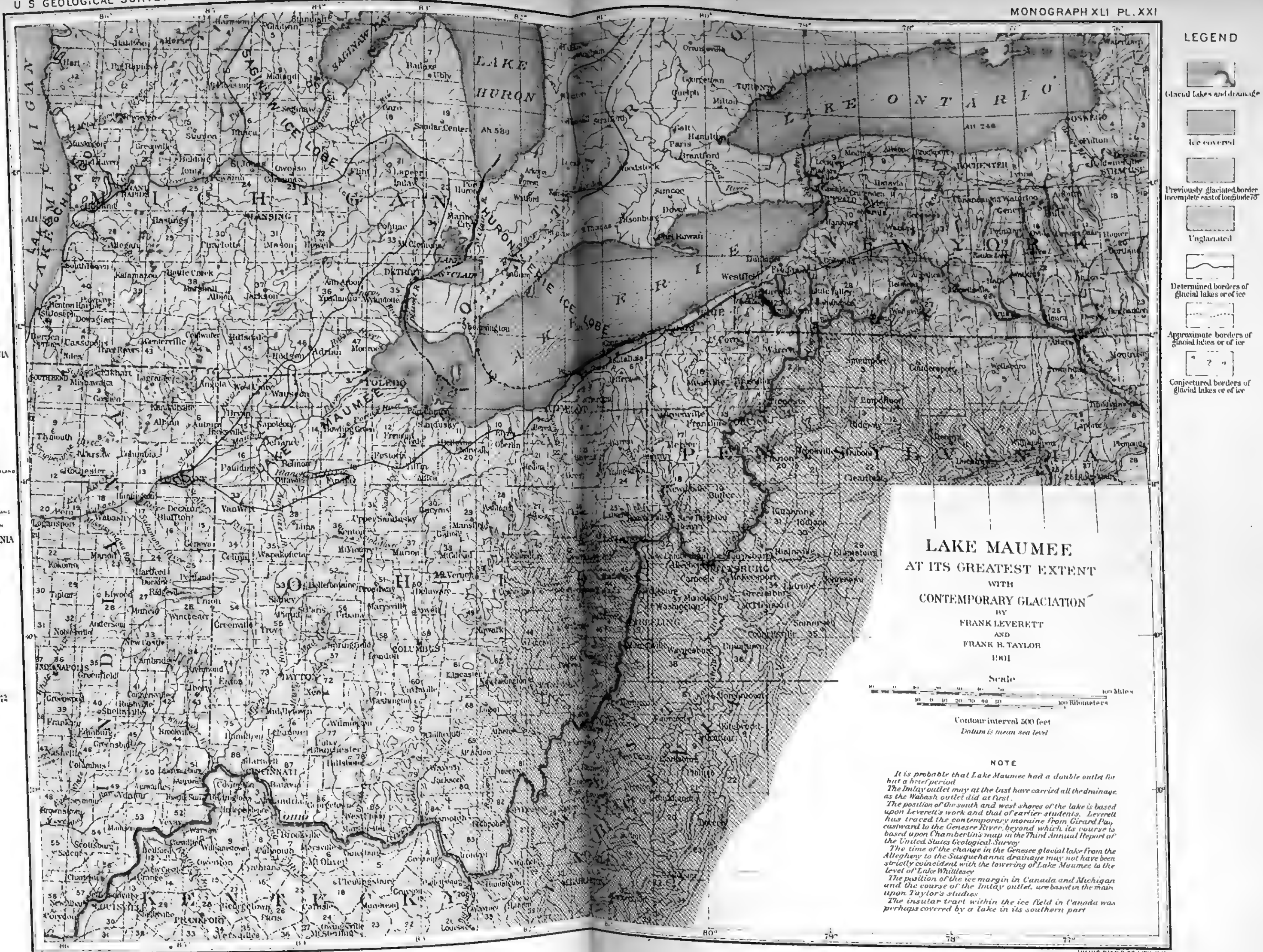

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JULIUS BIEN & CO LITH N Y

the beaches differ but a few feet in altitude (10 to 25 feet), and as topographic maps of the region they traverse have not been made, it will easily be seen that some uncertainty in identification is likely to be felt at points where but one beach is present. It is now known that considerable error of identification has appeared in publications already made by the writer as well as by others. Portions of what was supposed to be the first beach have, upon further examination, proved to belong to the second beach, the first beach having been found in faint form outside of and above the level of the second beach. The first beach has also in one case been taken for the second, and this has led the writer to a serious error of interpretation in the part of the lake border in Ohio between Findlay and Cleveland.[1] Railway altitudes have been pressed into service wherever obtainable, and these, together with a reexamination of much of the shore since the first publication (in 1892), enable the writer to correct some errors and to understand more fully the difficulties of correlation.

The Maumee beaches have been traced eastward from the Fort Wayne outlet to their termini on the south border of the Lake Erie Basin, as described below. They have been traced northward no farther than the Imlay outlet, in Lapeer County, Mich. On the west border of the lake only incidental notice was taken of the second beach, the writer's attention being concentrated on the determination of the extent of the lake and the position and character of its highest shore.

It was found that the border of the lake is usually marked by a cut bank or a gravelly ridge, and that the surface inside the lake border is perceptibly smoother than that outside. There are, however, a few places where the waters were too shallow to permit strong wave action, and at such places the margin can be only approximately determined. The extent of the lake is indicated in Pl. XXI, but as the scale of the map is small and the variations in the beach are of considerable interest, a somewhat detailed outline of the position and character of the beach will be given.

DETAILED DESCRIPTION.

At the point where the upper beach turns into the Fort Wayne outlet, $1\frac{1}{2}$ miles northwest of New Haven, Ind., it stands 15 to 20 feet above the floor of the outlet and several feet above the plain back of it. It presents a

[1] Am. Jour. Sci., 3d series, Vol. XLIII, 1892, pp. 287, 291–296.

single strong ridge from that point northeastward about to St. Peter's Church, 2 miles north of New Haven. It there assumes a complicated form, with three ridges more or less definite and of about the same height. The middle ridge is on the whole stronger than the outer and inner. These continue nearly 2 miles, to the western edge of Milan Township. The second beach is present much of the way to Milan Township, and stands about 15 feet lower than the first or upper beach. It is much weaker than the upper beach, probably because of the shallow depth of the lake in front of it.

From western Milan Township to Maysville, a distance of 7 miles, the upper beach is rather fragmentary or disconnected, and stands only 5 to 10 feet above the lake plain on its inner border. A common feature in this part of the shore is an overlap of ridges at the point of entry of streams into the old lake, a bar having been extended southward on the east or lakeward side of nearly every stream from the point where it entered the lake. These streams enter at intervals of about a half mile, and the bars extend south so far as to cause much of the shore to be lined with them.

At Maysville (Harlan post-office) a strong beach sets in, 150 to 200 yards wide and 10 or 12 feet high. It is bordered on the inner slope by a weak ridge or offshore bar, standing about 10 feet below its crest and 8 or 10 feet above the plain to the southeast. There are also some marks of wave action and a weak shore line to be seen on the tract immediately outside this strong beach, but this soon becomes merged with the main ridge upon passing east. The beach is well developed, largely as a gravel ridge, from Maysville to the State line, a distance of 8 miles, and the offshore bar is found to accompany it, for short distances, at frequent intervals. The beach is ordinarily 50 to 75 yards wide, and stands several feet above the lake plain on its inner border. It shows some overlapping at streams, but not to so marked a degree as in the district southwest of Maysville.

From near the State line of Indiana and Ohio to Hicksville, Ohio, a distance of 2 miles, there is scarcely a trace of the shore, as the water was probably too shallow for wave action; but immediately back of Hicksville a cut bank appears, which is distinctly developed for several miles. In the village of Hicksville the second beach is well defined, but is not so marked a feature as the cut bank of the upper shore line.

To one passing northeast from Hicksville along the Hicksville and Bryan pike the upper beach is in plain view, though at a distance of

one-fourth to one-half mile or more from the road, the cut bank being often 15 feet or more in height. The second beach, though lying near the pike, is developed for only short distances and is difficult to trace.

About 2½ miles from Hicksville a gravel ridge sets in that is 60 to 80 yards or more wide and 6 to 8 feet high. This follows the Bryan pike northeast one-half mile to the Six Points Church, and seems to be the upper beach. From the church northeastward to Lost Creek there are two well-defined gravel ridges, differing a few feet in altitude, but scarcely so much as the usual difference between the first and second beaches. The upper ridge lies north of the pike much of the way to Lost Creek, while the lower lies along or near it. The pike turns north after crossing the creek and comes to the upper beach about a mile from the creek bridge. The beach is exceptionally strong for a mile or more along the east side of Lost Creek, its breadth being about 150 yards and its relief 15 feet or more above the plain on its inner or southeast border, and several feet above the plain on its outer border. The lower of these two ridges is poorly developed from Lost Creek to Farmers Center, but from there northward to Bryan there is a rather definite ridge, which has the altitude of the second beach.

The upper beach crosses Dry Creek at its bend 3 miles southwest of Williams Center, and for nearly 2 miles above this point lies along the east side of the stream, causing it to take a southwestward course. It consists of a gravel ridge 100 to 200 yards in width and 10 to 15 feet in height. The ridge continues prominent and carries a large amount of gravel as far as Williams Center, but from there to Bryan gravel appears only in patches and the shore is mainly a cut bank. It passes about a mile west and a mile north of the court-house at Bryan, while the second beach passes through the court-house block.

From Bryan the upper beach, a cut bank, bears north of east to Beaver Creek, crossing that stream just above Pulaski. The second beach, a gravel ridge, bears northeast and crosses the creek about a mile below Pulaski, after which it follows up the east side of its valley to the village.

About a mile above Pulaski the upper beach takes the form of a gravel ridge and maintains it much of the way to West Unity. It stands usually 10 to 15 feet above the inner border plain, and 3 to 6 feet or more above the tract west of it. It passes through the north part of West Unity and has been opened extensively for gravel immediately east of the railway station.

From West Unity northeastward past Fayette into Michigan the upper beach lies but a few miles west of the Defiance moraine, and parts of that moraine rose above the lake level. It seems to have been protected to a great degree from wave action, and the beach is not so strong as farther south.

Near Adrian traces of a vigorous stream, which was discharged southward, were found, as shown by the bedding of its gravel deposits. It produced a remarkable amount of erosion considering the fact that it was flowing near the lake level. The west part of the city of Adrian stands on the scourway of this stream, its path being indicated by a level bowlder-strewn surface bordered on the west by a definite bank or bluff. Immediately south of the Lake Shore and Michigan Southern Railway a deposit of gravel sets in on this old stream bed and extends for 4 miles to the southwest, or nearly to the village of Sand Creek. The stream seems to have entered Lake Maumee near this village, for southwest of Sand Creek, along the west side of the Defiance moraine there is a sandy ridge at a level corresponding to the upper beach of Lake Maumee. It appears north of Black Creek near Packer and south of Black Creek from near Bimo to the vicinity of the State line, passing about a mile east of Morenci. It is a low ridge only 3 to 5 feet high, but is perhaps as strong as could be expected along a narrow bay. The west border of the bay can be traced easily from Sand Creek southwestward by a cut bank.

At the time the stream was operating, the ice sheet seems to have occupied the Defiance moraine, so that Lake Maumee extended but little north of the Ohio-Michigan State line. The production of this moraine, however, as already indicated, occupied only a part of the time when Lake Maumee was forming its upper beach. The beach has been found farther north on the inner border of that moraine.

The southernmost point on the inner slope of the northern limb of the Defiance moraine at which the upper beach has been identified is near Fairfield, Mich., 6 miles south of Adrian, but there are probably traces of it farther south in the midst of the sand area of northern Fulton County, Ohio, for parts of that area rise 20 feet or more above the level of the upper beach of Lake Maumee. The second beach is well developed at many points both on the east and west borders of that sand area, as indicated below. About a mile southwest of Fairfield a gravel ridge sets in which leads

northeastward through the north part of the village, and which furnished the site for the Fairfield geodetic station. It is 100 yards or more in width, and stands in places 10 to 15 feet above the plain on its inner border. The second beach lies within one-fourth of a mile south of it and leads through the south part of Fairfield. It is traceable beyond the southwest terminus of the upper ridge. Both ridges are developed for a short distance from Fairfield along the inner border of the Defiance moraine, which there runs nearly west to east. About 2 miles east of Fairfield the Defiance moraine swings abruptly to the north and becomes broken up into knolls and sloughs which are wave worn only at a few exposed points. The second beach, however, lies near the border between the moraine and the plain and is better developed.

The upper beach seems to be definite at but few points in the next 15 miles to the north, though more or less smoothing of the surface of knolls and slight terracing may be traced all along the inner slope of the Defiance moraine. The second beach is much better defined, and lies near the border between the moraine and the plain.

In northeastern Lenawee County, between Ridgeway and Macon, two ridges appear above the Belmore which seem to differ about 15 feet in altitude. The lower is about 35 feet and the higher 50 feet, by aneroid, above the Belmore beach at Ridgeway. The lower ridge is rather weak, but the higher one is strong and is maintained distinctly for a distance of fully 3 miles. It contains a sandy gravel and stands 5 to 10 feet above border tracts. On the west side there is a swamp, covering much of sections 18 and 19, Macon Township, and extending back to the border of the moraine. This, in all probability, was covered by lake water, the ridge in that case being at the place where the water became so shallow as to cause the waves to break. This ridge terminates near the bluff of a small stream about a half mile southeast of Macon. From the north end of the swamp, near Macon, the beach continues northward, along the border of the Defiance moraine, into Washtenaw County, being largely a cut bank, though gravelly ridges appear where small streams led down from the moraine to the lake plain.

The beach turns eastward in section 22, Saline Township, Washtenaw County, and passes through the central part of section 23 and north part of section 24, to Saline River, in the south part of section 13, being much of

the way a well-defined gravel ridge. East from the rivei the beach continues in a course north of east through York Township, traversing sections 18, 17, 16, 15, 14, 11, 12, and 1, and presenting throughout much of its course a well-defined gravel ridge 6 to 10 feet high and 50 to 100 yards or more in width.

In section 12, York Township, the beach turns northward and enters Ypsilanti Township near its southwest corner. For about 3 miles it presents a well-defined sandy ridge, passing in a direct course slightly east of north to the north part of section 20, where it terminates abruptly. But another ridge sets in outside this ridge and pursues a winding course northward through the western part of Ypsilanti Township, passing near the western limits of the city of Ypsilanti and coming to Huron River in the northwest part of section 5. About a mile east of this ridge, and at a slightly lower level, there are faint ridges of sand running through the southwest part of the city and along or near Summit Street nearly to the State Normal grounds in the northwest part. On the north side of Huron River there is a prominent sand bar setting in at Highland Cemetery nearly opposite the ridge at the Normal grounds. This bar trends east of north about a mile and connects with a beach leading in from the west which forms the continuation of the western or main ridge found south of the river. This beach can be traced westward across sections 33 and 32, Superior Township, nearly to the Huron River, and to within less than a mile of the end of the beach south of the river. The Huron River does not present a definite terrace at the level of this beach. This is due perhaps to the fact that the stream for a considerable period had its discharge southward from Ann Arbor to Saline River. Possibly the diversion to the present course did not occur until after Lake Maumee began to form this beach.

From the point where the bar connects with the beach in the west part of section 33, the beach takes a north-northeast course into Wayne County, passing through sections 34, 27, 22, 23, 14, and 12, Superior Township, and entering Wayne County in the northwest part of section 7, Canton Township. It consists usually of a low, gravelly ridge 3 to 6 feet in height, but there are frequent gaps where it is poorly developed or has the form of a cut bank.

The beach presents simply a cut bank for several miles after crossing into Wayne County, but from section 28, Plymouth Township, northeastward to West Rouge River, near Waterford, it usually consists of a low, gravelly

ridge. On the east side of Rouge River there is a conspicuous delta across which low bars pass northeastward, converging into a definite beach line. At the border of the river they are spread over a space nearly one-half mile in width.

The beach enters Oakland County near the southwest corner of Farmington Township and takes a somewhat direct course across that township, passing through the northwestern part of Farmington village and leaving the township in the northeastern part of section 12. It usually forms a definite gravel ridge 3 to 6 feet high, and 30 to 50 yards or more in width. It lies along the inner border of a sharply morainic tract. To the east of it there is a rapid descent to the Belmore beach, but the surface is remarkably smooth.

Immediately northeast of the point where the beach leaves Farmington Township there was a bay-like extension up to and beyond the village of Franklin, and in this the beach is not clearly defined. East of Franklin the shore follows the inner border of the moraine, and is usually in the form of a cut bank, as far east as the meridian of Birmingham. The second beach runs parallel with it, scarcely one-half mile distant, and presents usually a gravel ridge.

Near Birmingham there is considerable complexity caused by a till ridge and morainic hills which appear along the borders of East Rouge River. The till ridge at Birmingham is barely high enough to catch the second beach on its crest. Northeastward along the till ridge, however, it soon rises to the level of the upper beach, but the indications of wave action at that level are exceedingly faint, even where conditions seem favorable for the development of a beach. The lowering of the lake to the level of the second beach seems to have followed closely the withdrawal of the ice from this till ridge and the opening of the Imlay outlet. Indeed, it is probable that the opening of this outlet is the main cause for the lowering of the lake.

The second beach from Birmingham northward to the Imlay outlet is usually a gravelly ridge. It is exceptionally strong at Romeo and in the vicinity of Almont. It lies along the inner face of the till ridge just noted, from near Birmingham to Romeo. Farther north it traverses a tract of weak and interrupted till ridges. Its course is, however, somewhat direct from Romeo past Almont to Imlay. Near Almont it lies along the crest of a small till ridge that passes just east of the village.

The writer has not attempted to trace the beach beyond the Imlay outlet. That region is under investigation (season of 1900) by Taylor.

The portion of the second beach which appears on the border of the Defiance moraine in northern Fulton County, Ohio, and southern Lenawee County, Mich., remains to be described. The first clear indications of the beach were noted in the vicinity of Wauseon in a cut bank about a mile south of the town. From this point the beach was traced southwestward along the inner face of the Defiance moraine to within a mile of the south line of Fulton County, where it was found to cross over the moraine and turn northward along its outer or west face. The point where it crosses the crest is about 2 miles south of Pettisville. From this point southward, as already noted, the moraine has a very smooth surface, while to the north, in the part surrounded by the second Maumee beach, it is undulatory.

From the point where the beach crosses the moraine south of Pettisville northward to Tedrow, a distance of 8 miles, there are frequent developments of gravel ridges which have been opened extensively to obtain material for the roads. One of the gravel pits is a half mile east of Pettisville, another a mile northeast, and still others 2 to 3 miles farther north. From Tedrow northward into Michigan the beach is very indistinct, owing probably to the fact that there was only a narrow bay back of the Defiance moraine.

On the east side of the moraine the beach is developed at frequent intervals as a gravelly ridge from Wauseon northward into Michigan, its course being east of north as far as Winemeg and then nearly due north across the State line past Lyons, Ohio. It is poorly developed for 2 or 3 miles in the vicinity of Black Creek, but finds its continuation, as above noted, in the ridge that passes through the southern part of Fairfield, Mich. This beach has been extensively opened for gravel about 3 miles northeast of Wauseon, on the farm of Frank Blair, and also about a half mile southwest of Winemeg. From Winemeg northward into Michigan the beach is composed of a very sandy gravel unsuitable for road use.

Summing up the features of the portion of the Maumee shore between the Fort Wayne and Imlay outlets, it may be stated that the strength of the upper beach is on the whole decidedly greater where it lies outside the Defiance moraine (from near Fayette, Ohio, to the Fort Wayne outlet) than

along the inner border of that moraine, there being but few points in the latter situation where it attains the average development of the former.

The difference in strength or in continuity was recognized by the early settlers in the location of roads. The portion outside the Defiance moraine, from West Unity, Ohio, to Fort Wayne, Ind., was largely used as a highway and known as a "ridge road," but the portion in Michigan lying inside the moraine was utilized only for short distances, the gravel ridges being too disconnected to give the beach much advantage over border districts. The difference in strength may also be appreciated from the fact that the Maumee beaches had not attracted attention in Michigan, while the Belmore beach had been known from the early days of settlement. The courses of the Maumee shores in Michigan were in large part first determined by the writer in 1899, when he extended his studies into that region; but in Ohio and Indiana the Maumee shores were as early and as well known as the Belmore.

This difference in strength is not due to a more favorable situation for the development of a beach in the part outside the Defiance moraine, for the situation there, on the whole, seems less favorable, the slopes being in many places too gradual for effective wave action, a condition that seldom obtained in the part inside the Defiance moraine. The difference seems largely attributable to the greater time in which Lake Maumee washed the portion of the shore outside the Defiance moraine.

VARIATION IN ALTITUDE.

It has been known for some years that the shores of the glacial lakes which occupied the basins of the present Laurentian lakes have been subjected to a differential uplift, which causes the beaches to stand higher on the northern and eastern borders of the lake basins than on the southern and western. While uplift has probably produced the principal variation in altitude, there are variations not dependent upon deformations of the earth's crust which should be mentioned.

The lakes now occupying these basins show very little fluctuation through tidal action, the amount being but a few inches, and it is probable that the glacial lakes were not affected to any great degree. This factor may therefore be dismissed, as it would cause no perceptible variation in the altitude of the beaches. But fluctuations through variations in rainfall

amount to several feet, and such fluctuations are liable to have been still greater in the glacial lakes, though there are at present no recognized means of computing them. The present lakes show also a marked fluctuation or disturbance of level through the action of wind. Strong winds from the west have been known to drive the water from the western into the eastern end of Lake Erie, until the level at Buffalo became several feet higher than at Toledo. No doubt disturbances of this sort affected the glacial lakes, there being some evidence that the wind was from the same quarter. It is probable that the combined influence of the rainfall and the wind would give Lake Erie a variation of 12 feet and possibly 15 feet in level, and a beach is liable to be formed at the highest as well as the lowest level. The writer found the level of a well-defined storm beach at Westfield, N. Y., to be 12 feet above the ordinary low-water level of Lake Erie, and this may not represent the maximum height attained by storm beaches in other parts of the shore.

In addition to these factors of disturbance, the glacial lakes seem likely to have responded to the attraction of the ice sheet and to have stood appreciably higher near the ice margin than at points more remote. Woodward's computations[1] indicate that the deformation of the lake surface may have amounted to several inches per mile in the vicinity of the ice margin. It is therefore a matter of some importance to determine how much of the northeastward rise is due to ice attraction.

Turning now to the Maumee beaches, it is found that the upper beach stands about 775 to 780 feet above tide in the vicinity of the Fort Wayne outlet. Near the State line of Ohio and Michigan, 50 to 75 miles from the head of the outlet, several observations unite in giving the beach an altitude about 20 feet higher. The Fairfield (Mich.) geodetic station is 799 feet, while the railway stations at Fayette and West Unity, Ohio, which stand very near the level of the beach at those points, are 798 and 800 feet, respectively; but upon continuing northeastward from Fairfield, Mich., the altitude for the next 30 miles seems to become lower rather than higher. The aneroid determinations from several railway stations sustain this view, and an inspection of the profile of the Toledo and Ann Arbor Railway confirms it. This railway profile shows the altitude to be but 790 feet where it crosses the beach, 4 miles north of Milan. The altitude of the sand bar on

[1] See Bull. U. S. Geol. Survey No. 28.

Summit street, in Ypsilanti, is also 790 feet, as determined by city engineer's levels. Farther north, near Plymouth, the aneroid indicates that the altitude still remains at 790 feet. The next railway measurement is near Birmingham, 20 miles north of Detroit and 65 miles from Fairfield, where an electric-railway survey shows it to be 809 feet. Ten miles farther north, at Rochester, an electric-railway survey gives it an altitude of 820 feet. The second beach there is 780 feet. Twenty-five miles farther north, near the Imlay outlet, the second beach has an altitude of 849 feet, as determined by Spencer from the railway station at Imlay.[1] The marked differential uplift seems, therefore, to set in between Plymouth and Birmingham, about latitude 42° 30′.

The apparent exceptional altitude near the Ohio-Michigan State line is a matter concerning which an opinion can scarcely be ventured in the present state of knowledge. Had the beach terminated there just outside the Defiance moraine some reason might be found for attributing the increase in altitude to the attraction of the ice sheet; but the fact that the beach continues farther and seems to become a little lower unsettles this view to some degree. There is need for more accurate as well as more numerous determinations of level to make certain whether the beach declines a little in passing north from Fairfield. The altitude of the neighboring parts of the Belmore beach may prove of service in settling the question of ice attraction. Should the Belmore beach show a corresponding exceptional altitude in the vicinity of the Ohio-Michigan line it would strongly oppose the view that ice attraction had been influential in giving the Maumee beach its altitude, and would indicate that crust warping was the cause, for ice attraction can not be supposed to have had the influence upon that part of the Belmore beach that it might have had upon this part of the Maumee, as the ice sheet had probably withdrawn about to the limits of Lake Huron and had become greatly reduced in thickness before the Belmore beach was formed; but on this beach careful measurements have not been made. Until refined measurements have been made on each of the beaches it seems hazardous to venture an opinion on this point.

The second beach seems to stand about 760 to 765 feet above tide from the Fort Wayne outlet northeastward to Bryan, Ohio, and to be no higher

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[1] Am. Jour. Sci., 3d series, Vol. XLI, 1891, p. 209; see also F. B. Taylor: Bull. Geol. Soc. America, Vol. VIII, 1897, p. 37.

in the vicinity of Wauseon and Pettisville, where it crosses the Defiance moraine; but at Fairfield, Mich., it stands only 20 to 25 feet lower than the upper beach, or about 775 feet above tide. Near Ridgeway it seems to be about 775 feet, being only 15 feet below the upper beach. At Birmingham, as already noted, it is 780 feet, or 29 feet lower than the neighboring part of the upper beach, while at Imlay it is 849 feet.

THE SOUTH SHORE OF LAKE MAUMEE.

In the examination of this shore attention was given principally to the extent and character of the upper beach. The second beach seems, however, to be developed along much of the shore. From near Cleveland eastward into Pennsylvania, as indicated below, it appears to be the only beach of Lake Maumee, that part of the lake basin having been occupied by the ice sheet at the time the upper beach was forming.

DETAILED DESCRIPTION.

Along the south border of the Fort Wayne outlet east from Fort Wayne there are two ridges of sand differing a few feet in level. The lower and more fragmentary one is utilized by the Fort Wayne and Van Wert road for a part of the way between Fort Wayne and New Haven. The higher one lies a short distance south, along the base of the bluff of the outlet. The lower ridge is only 3 to 5 feet in height, but the higher one is generally 6 to 8 feet. The lower ridge appears to be low enough to connect with the second beach, but the higher one seems to be above the level of that beach.

On the east side of the Sixmile channel there is a very prominent hook where the beach turns into the channel. A gravel pit exposes its structure to a depth of 17 feet. The upper 5 feet is quite sandy, but below this depth there is gravel which shows cross bedding with southward dip. The beds also dip toward each side of the ridge in anticlinal fashion. The crest of this recurved ridge stands about 25 feet above the Nickel Plate Railway station at New Haven, or 786 feet above tide. It rises a few feet above the usual altitude of the upper beach and probably stands at least 5 feet above the highest lake level.

From this hook eastward the upper beach is very sandy and in places low dunes appear. Wells show the sand to have a depth of 9 to 18 feet. The ridge rises abruptly about 15 feet above the lake plain on the north, and 6 to 8 feet above a sag on the south. The sand ridge terminates near

the southeast edge of New Haven, and for 2 miles east there is a cut bank to mark the position of the shore. This bank is 10 feet or less in height, gradually decreasing in strength eastward until it fades out. A bar known as "Irish Ridge" sets in north of the point where this bank fades out and leads eastward a distance of 3 miles, from near the center of section 10 to the northwest part of section 13, Jefferson Township. It stands about as high as the upper beach, its western end, near the Nickel Plate Railroad, being 779 feet, and it seems to have in a measure protected the shore back of it from wave action.

The beach reappears near a Catholic church about a mile east from where the cut bank dies out. It consists of a low gravelly ridge, standing only 3 to 5 feet above the bordering plain, and is only 30 to 40 yards in width. Near Zulu it increases in strength and stands in places 6 to 10 feet above the plain north of it. There is here a thin gravel coating on the top of a cut bank. The beach runs south to Flat Rock Creek in section 36, Jefferson Township, and there terminates abruptly. There seems to be no trace of the shore for about 2 miles east of this creek. The surface is very flat and there was probably so little depth of water at the lake border that wave action was weak.

The beach reappears east of East Flat Rock Creek, in the southeast part of section 32, Jackson Township. From there to the State line of Ohio and Indiana it consists mainly of a low cut bank 5 to 6 feet in height, gravel deposits being meager. In the vicinity of the State line a series of four nearly parallel, low, gravelly and sandy ridges are found which differ but little in altitude, and were probably formed in succession from south to north at the highest lake stage, though the northern one may pertain to the second beach. The northern ridge enters Ohio in the southwest corner section of Paulding County; the southern enters Ohio 2 miles farther south, near the line of sections 6 and 7, Tully Township, Van Wert County. The two southern ridges seem to be only locally developed, but the two northern are quite persistent for several miles into Ohio.

Of these two ridges the inner one is the weaker and is a few feet lower (perhaps 10 feet) than the outer or southern one. The space between the two ridges is a mile or less. The northern one is followed by the Fort Wayne and Van Wert road from the State line to a point 1½ miles northeast of Convoy. The ridge there leads eastward, while the road turns

south to the southern ridge. The northern ridge seems to die out near the line of Tully and Union townships, but the southern is well defined from near Convoy to Van Wert, and is followed by the Fort Wayne and Van Wert road. The southern ridge from the State line to Van Wert is seldom less than 50 yards and in places is 150 yards in width. It stands 5 to 10 feet or more above bordering plains and in places is sandy. The northern ridge is only 30 to 50 yards wide and is very gravelly.

At Van Wert the beach is only about 5 feet high and 30 yards in average width, being below its usual strength. The writer was in the city in 1891 when pipes for waterworks were being laid, and found that the beach carries a clayey gravel at the surface, beneath which, at a depth of 2 or 3 feet, clear gravel and sand set in. There are frequent and abrupt changes from sand to gravel and the beds show plainly wave action from the north.

About 2 miles east from Van Wert the beach becomes exceptionally strong and continues so for 5 miles in curving from a north of east to a south of east course. It rises 6 to 10 feet above the plain north of it and is largely a cut bank. At Dog Creek and also at Little Auglaize River gravelly material brought in by the streams has been worked upon by the waves and given a regular front on the lakeward side, standing about 10 feet above the lake bottom.

On the borders of Dog Creek Valley two beach ridges appear, which are separated by a space scarcely a half mile wide and which become united both to the east and west from the creek valley. They differ but little in altitude, though the south one appears to be a few feet the higher. From Little Auglaize River eastward, toward Delphos, there are two distinct beach lines, each of which is weak. The northern, which is the more continuous, is followed by the Van Wert and Delphos road; the southern leads southeastward from the Little Auglaize River, along an angling road 2 miles to the southwestern part of section 26, Washington Township, where it dies out in a plain; but east of this point two small ridges were noted, one of which crosses the Pittsburg, Fort Wayne and Chicago Railroad about a mile west of the canal, while the other lies south of it in section 26.

In the vicinity of Delphos the shore is not well defined, and Jennings Creek does not carry such a conspicuous delta as appears on Little Auglaize River and Dog Creek.

Between Delphos and the Auglaize River there are only faint developments of the two ridges, but immediately east of Auglaize River both ridges become strong. The southern or outer ridge comes to the river at the crossing of the Pittsburg, Fort Wayne and Chicago Railroad, and takes a northeastward course from there to Gomer. It is a low sandy ridge 5 or 6 feet in height and about 100 yards in width. Parallel with it on the north and about a mile distant is the second ridge, which is followed by the Bucyrus and Delphos road. It appears by aneroid measurement to be about 10 feet lower than the outer ridge, and it has about the same strength. From Gomer to Columbus Grove the two ridges are well defined, though the southern is not so continuous as the northern. The northern or inner ridge leads through the business part of Columbus Grove and the outer one near the southern limits of the village. The southern ridge is poorly defined for 3 miles east of Columbus Grove, but then reappears in considerable strength and continues strong for about 2 miles to Riley Creek, coming to the creek 3 miles south of Pandora. The ridge was not found farther east, and the lake shore probably returns northward to the northern ridge at Pandora. The northern ridge leads directly to Pandora from Columbus Grove along the line of the Bucyrus and Delphos wagon road.

Between Pandora and Findlay the beach is very strong as far as Benton Ridge, there being usually a bank 10 to 20 feet high, capped by gravel several feet in depth. From near Benton Ridge to Findlay the bank is but 6 to 10 feet high and the deposits are rather sandy. This part of the beach borders a narrow bay south of the Defiance moraine, and in view of its situation is remarkably strong.

North from Findlay the Defiance moraine rises nearly 50 feet above the level of Lake Maumee, but within about 10 miles west it drops nearly to the highest lake level and continues near that level for about 10 miles farther. It is there crossed by a beach which stands at the level of the second beach, 760 or 765 feet above tide. The upper beach, which is about 15 feet higher, is apparently represented chiefly by sandy accumulations of irregular form, which follow the crest of the moraine eastward to the point where it rises above lake level and then pass eastward to Findlay along the south face of the moraine.

The second beach is strongly developed along the south face from near Gilboa northwestward to the place where it crosses the crest 2½ miles northwest of Leipsic. It contains a large amount of gravel and has been

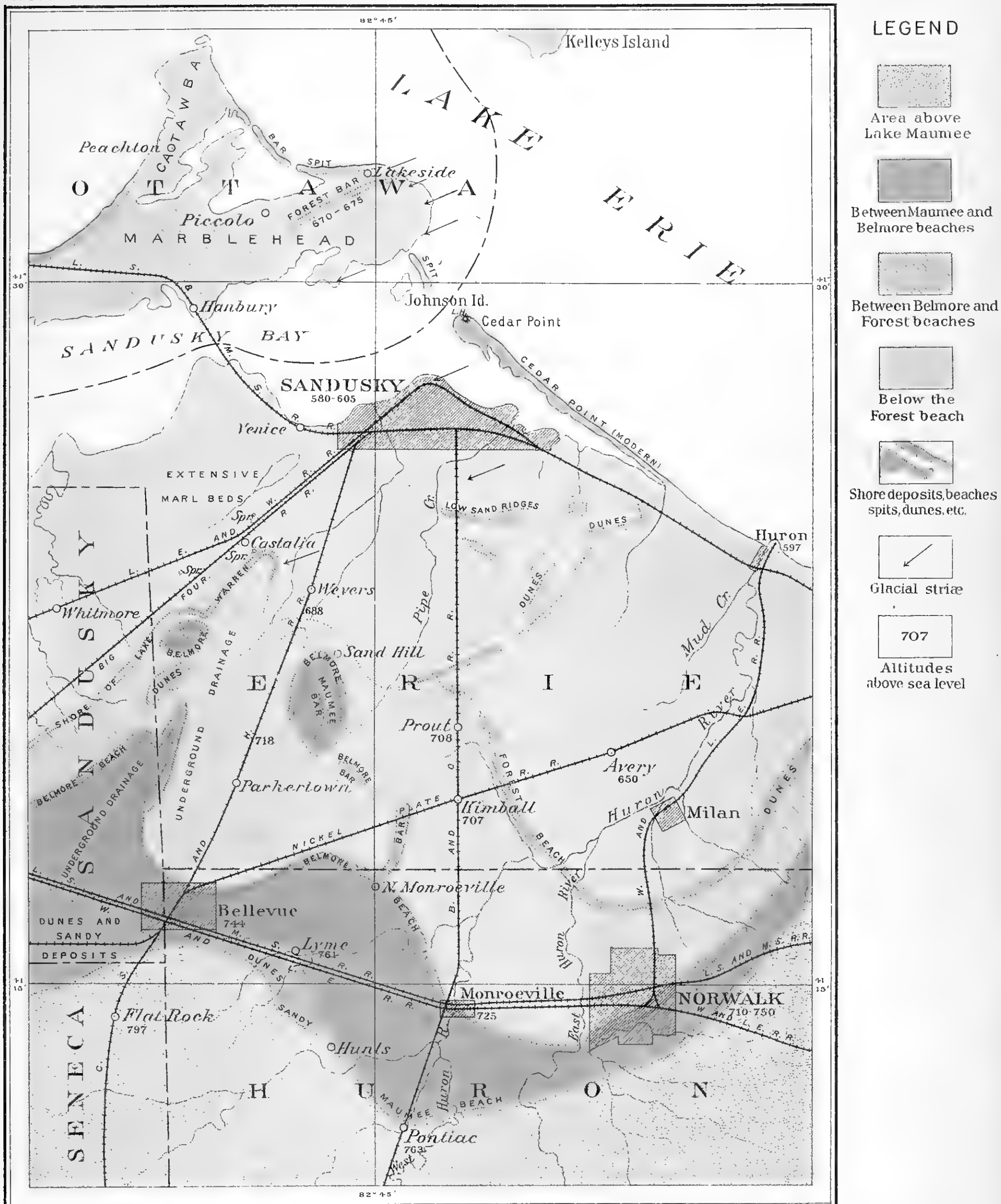
opened for road ballast at many points. The gravel pits show clearly that the gravel was washed up against the moraine from the southwest. Where crossbedding occurs the dip is uniformly toward the moraine. The gravel can not, therefore, be an outwash from the moraine. The form of the beach is also in itself sufficient evidence that the gravel is a shore deposit. In the vicinity of the point where the beach crosses the crest of the moraine, and for several miles eastward along the north face of the moraine, a cut bank 10 to 15 feet high was found. This in places carries a gravel deposit which is nearly or quite up to the level of the upper beach, but the base of the bank is as low as the second beach.

The course of the beach is south of east for several miles from the point where it crosses the Defiance moraine. It then swings with the moraine to a course north of east and leads through McComb and Van Buren to Fostoria. The upper and second beaches were not clearly differentiated in this part of the shore, though two ridges were observed in the interval between McComb and Van Buren which appear to differ a few feet in altitude. At Van Buren there is a cut bank 12 to 15 feet high, the base of which seems to be near the level of the second beach and the top near the level of the upper beach. Two ridges were also observed west of Fostoria, the southern being near the line of the Baltimore and Ohio Railroad and the northern along a wagon road about a half mile north. These differ apparently less than 10 feet in altitude, and both lie near the level of the upper beach, 775 to 780 feet above tide.

From Fostoria the shore bears south of east through Bascom to Tiffin. There are in places two ridges, differing at most only a few feet in altitude. Neither ridge is strong, the usual height being 3 to 5 feet. A cut bank of similar height occurs along part of the shore. The weakness of the ridge in this part of its course seems largely due to the direction it takes. It is found that, in general, the weakest part of this and other shores of the glacial lakes in the Erie Basin are where the shore fronts toward the northeast.

From Tiffin the shore takes a northeastward course into southeastern Sandusky County, coming to the Lake Shore and Michigan Southern Railway about 3 miles west of Bellevue, from which point it turns eastward into Bellevue. This part of the shore is marked by a strong beach, as is usual where the shore fronts toward the northwest.

To the north and northeast of Bellevue there were small islands in the



JULIUS BIEN & CO. LITH. N.Y.

MAP OF BEACHES NEAR SANDUSKY, OHIO

BY FRANK LEVERETT

1901

Scale

0 5 10 MILES

0 5 10 KILOMETERS

lake, one being on the line of Sandusky and Erie County about 3 miles north of Bellevue, another 1 to 2 miles south of Castalia, and a third about 5 miles northeast of Bellevue immediately west and south of Sevenmile House. The beaches are well developed on the east, north, and west sides of these islands, but are rather obscure on the south side. The accompanying map, Pl. XXII, shows the character of the topography of the region between Bellevue and Sandusky, the Belmore and Forest beaches, as well as the Maumee, being complicated because of the uneven surface which that region presents.

The shores were irregular along the south border of Lake Maumee for about 3 miles each side of Bellevue, where the surface is rather uneven because of low rock hills and ridges. A smoother tract sets in 3 miles east of Bellevue, and the beach extends southeastward past Hunts Corners to Pontiac, in northern Peru Township. There are sand dunes as well as gravel deposits in this broken tract near Bellevue. Some of these are 15 or 20 feet in height, and they may extend in places slightly beyond the limits of the lake.

Near Pontiac the shore turns eastward and crosses both branches of Huron River about a mile south of the north line of Peru Township. The course is then northeastward through the northwest part of Bronson Township into Norwalk Township. The beach passes through the extreme southeastern part of the city of Norwalk and a mile east of East Norwalk. It leaves Huron County at the northeast corner of Norwalk Township and continues northeastward through Berlinville to Berlin Heights. Thence its course is slightly north of east past Axtel into Lorain County, about parallel with the shore of Lake Erie and distant from it scarcely 4 miles. It crosses Vermilion River about 2 miles below Birmingham and continues eastward across southern Brownhelm and Amherst townships to the west part of Elyria Township, passing about 2 miles south of North Amherst. This part of the shore from Huron River northeastward is exceptionally strong. It was not only exposed to the heavy waves raised by the west winds, but carried a sufficient depth of water along the shore to prevent the waves from breaking until they had reached the beach. There is frequently a cut bank 10 to 15 feet or more in height, along or near the base of which a gravelly beach appears. In the vicinity of the Huron River there is a space of a half mile or more between the cut bank and the gravelly beach,

but the latter seems to be of about the same height as the base of the bank. Possibly the bank alone represents the upper beach and the gravel deposits the second beach, but the difference in level appears to be less than is generally found between the two beaches. However, only aneroid determinations have been made, and the difference may be more than it now seems to be. For 2 or 3 three miles east of Berlin Heights there is a prominent ridge of sandy gravel standing 8 to 10 feet above the tract south of it, and still more above that on the north. This is succeeded toward the east by a cut bank that extends about to Axtel. Along this cut bank there a remarkable number of bowlders, showing, apparently, that the till in which the bank is cut was very stony. From Axtel eastward two ridges appear which differ a few feet in level, and perhaps represent the upper and second beaches. They are found both east and west of Vermilion River, though they are more closely associated east of the river than west.

Much of the shore of Lake Maumee from near Elyria to Cleveland was traced in detail by A. A. Wright, for the Ohio Geological Survey.[1] The double phase of the shore was clearly brought out both to the west and east of Elyria. Two ridges west of Elyria differing a few feet in level lead southward to the West Branch of Black River, the inner and weaker coming to the river about 3 miles south of the Belmore beach in Elyria, and the outer about 1½ miles farther up the river. The outer ridge is well developed between the West and East branches of Black River, passing Patterson Station and coming to East Black River opposite Laporte. The inner ridge does not appear between these streams, but sets in on the east bluff of East Black River. Both ridges are nearly continuous from East Black River to Rocky River. The upper is known as Butternut and the lower as Chestnut ridge. They differ 15 to 20 feet in altitude, the upper being in harmony with the upper beach to the west, about 780 to 785 feet above tide, and the lower with the second beach, 765 to 770 feet. The upper beach is double for about 3 miles northeast from Laporte, but the two members seem to be nearly identical in level. The upper beach comes to the west bluff of Rocky River near the junction of the two forks of that stream, 3 miles northwest of Berea, and follows nearly the bluff of the stream northeastward for 3 miles, when it crosses to the east side and leads eastward with a curving course convex to the north, past West Park

[1] Geology of Ohio, Vol. II, 1874; map opposite p. 58.

Station on the Lake Shore and Michigan Southern Railway, to North Linndale. The second beach comes to Rocky River immediately west of West Park. Upon crossing the river it becomes a cut bank and curves around nearly concentric with the upper beach to Big Creek at North Linndale, crossing Lorain street about a half mile west of the present city limits of Cleveland.

Each of the beaches is strong from Black River to Rocky River. The upper usually presents a cut bank 5 to 10 feet high, though in places assuming the form of a gravel ridge. The second beach is commonly a gravel ridge 50 to 100 yards wide and 5 to 10 feet high. The course of the electric railway from Cleveland to Elyria is such as to give an excellent view of each of these beaches from Rocky River nearly to Ridgeville. It then follows the Belmore beach to Elyria.

From Big Creek at North Linndale eastward to Brighton there are traces of both the Maumee beaches.[1] The upper beach is ordinarily a wave-cut bench with but little gravel. It leads through the southern part of Brighton, passing near the tollgates on the Parma road and the "Town line" road. The interval between Brighton and the Cuyahoga River is so broken by ravines that the course of the upper beach was not ascertained. The second beach, after crossing Big Creek about a mile east of North Linndale, is developed for a mile or more as a gravelly ridge. It then becomes a cut bank, and leads through the midst of Brighton. It leads southeastward along an angling road to the Cuyahoga River bluff near the north edge of Independence Township.

Upon passing to the east side of the Cuyahoga and ascending the bluff along the "Warner road" a beach is found at the top of the bluff on the north side of a small eastern tributary, about one-fourth mile south of the present limits of the city of Cleveland. The barometer indicates that it has the altitude of the second Maumee beach. A gravel pit shows a depth of 8 or 9 feet of fine gravel. From this point the lake shore passes northward along the east side of Mill Creek, while the "Warner road" rises above the level of the upper beach. This road comes down to lake level again at its intersection with Turney avenue, just south of Mill Creek. The city levels make the altitude 207 feet above city datum, or about 780 feet above

[1] The first tracing of the Maumee beaches through the city of Cleveland was by Upham, whose observations and map are presented in the Bulletin of the Geological Society of America, Vol. VII, 1896, pp. 340–345, plate 15. The writer also followed them through the city as here indicated in 1899.

tide. It appears, therefore, to be the upper beach. The lake extended no farther up Mill Creek than this road, for the creek here comes out of high country into the old lake plain. From Mill Creek the old shore passes northward near the line of the Cleveland and Pittsburg Railroad to Newburg station, where its altitude is 212 feet above city datum, or about 785 feet above tide. It continues north near the rolling mills and crosses Union street where Patton street leads north. The top of the bank there is 210 feet above city datum. The upper beach seems to be represented still farther north by sand deposits near the corner of South Woodland and Woodland Hills avenues, as the altitude there is 208 feet above city datum. Farther north, in the vicinity of the Garfield monument, there is a steep bank extending from near the level of the second beach up to a level above the upper beach. The sandy deposits along the base of this bank apparently belong to the second beach. The upper beach is much weaker from the terminus of the Cleveland moraine at North Linndale eastward through the city of Cleveland than it is to the west, its strength being less than that of the second beach. This change in strength seems attributable to the longer time in which the lake held this level in the part of the shore west of the terminus of the moraine.

From Cleveland eastward the presence of the upper beach is rather uncertain. There are indications of the continuation of Lake Maumee as far east as the vicinity of Girard, Pa., and the barometric determinations suggest a double shore for a part of the distance, with levels differing about as in the region to the west. But in the absence of topographic sheets or accurate levels some uncertainty is felt concerning the presence of the upper beach east of the vicinity of Cleveland. Possibly it extends no farther east than the terminus of the Euclid moraine, 10 miles east of Cleveland.

Before continuing the description of the Maumee beaches to the east of Cleveland attention should be called to a prominent terrace in the east part of Cleveland, on which the Garfield monument stands, and which has been referred to by Newberry as a lake terrace.[1] This prominent terrace, which stands about 250 feet above Lake Erie,[2] or nearly 40 feet above the

[1] Geology of Ohio, Vol. I, 1873, pp. 181–183; Vol. II, 1874, pp. 59–60.

[2] It is reported in the Geology of Ohio to be 210 to 220 feet above the lake, but the city levels show its altitude south of the Garfield monument, at the intersection of Mayfield road with Kent road, to be 247 feet above Cleveland city datum, which is near the mean level of Lake Erie.

highest shore of Lake Maumee, is better defined for several miles east from Cleveland than any terraces at levels corresponding with either of the shores of Lake Maumee, the width being from an eighth of a mile to nearly a half mile. This terrace is as flat as the bed of a stream, and is usually bordered on the southeast by an abrupt bank. It may have been formed by a stream passing westward between the ice margin and the escarpment before the ice sheet had withdrawn from the foot of the escarpment. It has not, however, been examined with sufficient care to justify a positive interpretation of such an origin.

For some miles east from the east part of Cleveland the escarpment is so abrupt that the Maumee shores are marked simply by narrow benches cut in its face at the salient parts of the escarpment. About midway between Lake View Cemetery and the post-office at East Cleveland a bench was found at what appears by aneroid to be the level of the upper Maumee beach. It is much narrower than the bench above it, just mentioned, that leads westward past the Garfield monument. A similar narrow bench is found at about the same level south of East Cleveland. In each place there are only scattered pebbles on the bench, resting directly on the shale. Between East Cleveland and Euclid a narrow bench was found along the face of the escarpment, which by aneroid appears to be at about the level of the second Maumee beach. It carries a small amount of sand and gravel. East of Euclid there are slight developments of a bench having apparently the level of the upper beach, for it stands 40 to 50 feet above the Belmore beach. Whether it was formed by the lake is not certain.

Near the line of Cuyahoga and Lake counties the escarpment loses its boldness and drift deposits of considerable thickness set in. The Belmore beach is well developed, but the Maumee shore is rather weak. A gravel ridge was found, however, near the brow of the escarpment southeast of Wickliffe, which seems to have the level of the second Maumee beach.

From the Chagrin River eastward nearly to Grand River the Belmore beach is cut into the inner slope of the Euclid moraine, and in places has a bank 20 to 40 feet high, but the Maumee shore is very weak and fragmentary, though the moraine rises high enough to catch it.

East of Grand River from near Madison to the vicinity of Saybrook a distinct beach is found above the Belmore, having apparently the level of

the second Maumee beach. It is finely developed at a cemetery a half mile south of Madison and seems to be about 25 feet higher than the Belmore beach. The beach here is 100 to 150 yards wide and stands nearly 10 feet above the plain north of it. It has been opened for gravel to a depth of 10 feet. A mile farther east it presents a cut bank nearly 10 feet in height, but from the vicinity of Unionville nearly to Saybrook there is usually a gravelly ridge 3 to 6 feet or more in height. For 5 miles east from Madison it stands but one-fourth to one-half mile south of the Belmore beach. The courses of the beaches there diverge, until near the corners of Geneva, Saybrook, Harpersfield, and Austinburg townships the Maumee shore is a mile south of the Belmore beach. From these township corners toward Saybrook they converge and become united in a single prominent bank south of that village.

From Saybrook to Ashtabula the bank is 20 to 30 feet or more in height. Its base is followed by the Belmore beach, while its top stands near the level of the second Maumee beach. There are sandy deposits along the brow, which may perhaps represent the second Maumee beach. Sand deposits were found, however, near the standpipe of the Ashtabula waterworks at a higher altitude than the second Maumee beach, the altitude of the standpipe, as given by levels at the city engineer's office, being 216 feet above the zero of the Government gauge at Ashtabula harbor, and the crest of the sand ridge near it, 2½ feet higher, or about 790 feet above tide. This altitude is in harmony with that of the upper Maumee shore, but is about 20 feet above the second Maumee beach of that region. Whether it should be taken as an indication that Lake Maumee extended to this point at its upper stage is not clear. Being composed entirely of sand, there is a possibility that it was formed by wind action, in which case it may stand considerably above the lake level.

East of Ashtabula Creek the Belmore beach is finely developed south of the Nickel Plate Railroad at an altitude of 170 to 175 feet above Lake Erie. South of it there appears to be wave cutting on the inner slope of the Ashtabula moraine at about 195 feet above Lake Erie, or 765 to 770 feet above tide. About midway between Ashtabula and Kingsville sand knolls set in at a level 190 to 200 feet or more above Lake Erie and continue eastward to Kingsville. They are 10 to 30 feet high and cap the highest points on the moraine. Near Kingsville a well-defined gravelly

beach appears at the north border of the sand, at the level of the second Maumee beach, about 190 feet above Lake Erie. The sand knolls may have been drifted back from this beach by the wind, though it is barely possible that they may represent the upper stage of Lake Maumee, whose level they reach. In this connection it may be remarked that whether or not Lake Maumee reached this far east at its highest stage, the streams and small lakes held between the ice margin and the escarpment to the south are likely to have stood about as high as the upper beach, and these may be responsible for some of the sand deposits. The gravel beach has been opened for road material in a field north of the Kingsville school building. It extends as a well-defined gravel ridge for about 1½ miles west from Conneaut Creek at Kingsville. Upon crossing Conneaut Creek one finds the second Maumee beach at intervals on the inner face of the Ashtabula moraine, between there and the Ohio-Pennsylvania line. It is usually simply a wave-washed surface without a definite ridge, but occasionally a gravel ridge appears. Such a ridge was noted 3 miles west of the State line, but it is there developed for a distance of only about 100 yards along the brow of a cut bank which extends down to the level of the Belmore beach. A smooth surface, apparently wave washed, extends back in that vicinity 100 to 200 yards or more from the brow of this cut bank. A more prominent ridge was developed for a distance of about one-half mile in the vicinity of the State line. Here also it is at the top of a cut bank back of the Belmore beach. Its altitude as shown by the Girard topographic sheet is above 760 feet. By aneroid it is 25 to 30 feet above the Belmore beach, or 770 to 775 feet above tide. The grading of the State line wagon road has exposed the Maumee beach to a depth of 7 or 8 feet. The beach rises 5 to 6 feet above a sag back of it, but within 100 yards south the Ashtabula moraine sets in and rises above the level of the bank.

From the Ohio-Pennsylvania line this gravel beach extends east about one-fourth of a mile. Sandy knolls and ridges then set in, which continue east about a mile along or near the brow of a cut bank back of the Belmore beach. They are 10 to 20 feet high and are confined to a strip a half mile or less in width. The bank seems to be continued past West Springfield station in low sandy ridges, some of which, just north of the station, have been opened for molders' sand. The altitude here is 777 feet.

From West Springfield eastward to Girard this beach is more fragmen-

tary than to the west. There are, however, low gravelly ridges in the vicinity of Cross station which seem to mark its continuation, and a gravel deposit on the west bluff of Elk Creek opposite Girard seems also to belong to this beach.

From Girard eastward the writer was accompanied by F. B. Taylor in a search for the second Maumee beach. There appeared to us to have been some wave action in the southeastern part of Girard at the inner border of a moraine, but from that point to Fairview beach phenomena, if present, are very obscure. At Fairview there is a gravel deposit at about 770 feet which is apparently a delta formed by Trout Run. It is immediately back of the Belmore beach and yet stands 25 to 30 feet above it. It may have been formed in connection with the Maumee beach, but of this some uncertainty was felt. This uncertainty increased as we passed eastward to Swanville, for the morainic knolls there extend down to the border of the Belmore beach, and so far as we could detect show no traces of wave action at a level corresponding to the Maumee beach. Nor did we find anything suggesting wave action above the Belmore beach between there and Erie. In the southwestern part of Erie, however, is a plain south of the waterworks reservoir at the right altitude for the Maumee beach, where there are traces of water action, either by waves or by a current. There is not a well-defined beach, but a flat tract which leads westward from Mill Creek to Cascade Creek has a definite south border rising in places like a bank. It seems to us not unlikely that glacial waters may have discharged westward through this flat tract while the ice sheet was occupying a range of drift knolls on which the reservoir stands. We certainly should not cite this place as a clear indication of the presence of Lake Maumee.

Continuing eastward into New York we were unable to find any definite shore line above the Belmore beach. There were a few places where the drift surface seemed to have been subjected to leveling by water action, but these appear at various altitudes and are chiefly above the level which Lake Maumee would have reached. They seem better explained as the work of water escaping along the ice front while it was still closely bordering the escarpment. The shore of Lake Maumee appears therefore to terminate between Girard and Erie, Pa., and it is doubtful if the lake had even a transient extension farther east. By the time the ice sheet had withdrawn beyond Erie the water had probably fallen to the level of the Belmore beach, and Lake Whittlesey had succeeded Lake Maumee.

VARIATIONS IN ALTITUDE.

There appears to have been very little warping of the south shore of Lake Maumee west of the Ohio-Pennsylvania line. The slight variations displayed by each of its beaches are no greater than may be found along the present shore of Lake Erie; but near the Ohio-Pennsylvania line a differential uplift had caused the beaches to increase perceptibly in altitude in passing eastward. This, however, affects only the second beach of Lake Maumee, and that for but a few miles. The discussion of the uplift may therefore be taken up to better advantage in connection with the beaches of Lake Whittlesey and Lake Warren.

The upper beach of Lake Maumee stands about 775 to 785 feet above tide throughout its course from Fort Wayne to Cleveland. The second beach stands about 765 feet above tide in the same interval, but rises about 10 feet between Cleveland and the Ohio-Pennsylvania line, and attains near its terminus in northwestern Pennsylvania an altitude of about 780 feet.

RELATION TO THE ICE SHEET.

The dwindling and disappearance of the beaches of Lake Maumee in passing from northeastern Ohio into northwestern Pennsylvania, taken in connection with the fact that the ice sheet withdrew in that direction, makes it practically certain that the eastern limits of the lake were determined by the ice sheet. It appears, also, that the presence of the ice sheet in the low places on the rim of the Erie-Huron basin in Michigan and of the Ontario basin in New York caused the lake to rise to the Fort Wayne and Imlay outlets. The withdrawal of the ice sheet from these low places, as indicated farther on, brought them into use as outlets and thus allowed the lake level to become lower. It is probable, also, that the Lake Escarpment morainic system was in process of formation during most of the time that Lake Maumee stood at the level of the second beach, and that the Cleveland and Defiance moraines were formed while it occupied the upper beach.

The strength of the portion of the upper beach inside the Defiance moraine is about as great on the south shore as the portion outside that moraine; but on the west shore, as already indicated, the portion inside the Defiance moraine is decidedly weaker than that outside. It is not difficult to find an explanation for the strength of the portion of the south shore inside the Defiance moraine. Much of this part of the shore fronts

the northwest, while outside the Defiance moraine much of the shore fronts the northeast. An examination of the beaches has shown that portions which front the northwest are uniformly stronger, other conditions being equal, than those fronting the northeast. This is true not only of the Maumee beaches but of the Belmore beach, the beaches of Lake Warren, and the beach on the present shore of Lake Erie. This seems to indicate that heavy waves were chiefly raised then, as now, by the winds from the west. In addition to this advantage of frontage toward heavy seas, the portion inside the Defiance moraine had on the whole deeper water near the shore than that outside, so that large waves were less liable to have been broken at some distance from the shore than in the district outside the moraine.

CAUSE FOR TWO BEACHES.

The cause for the occurrence of two beaches in connection with Lake Maumee, as already suggested, is apparently found in the opening of the Imlay outlet, which increased the capacity for discharge and produced a lower level than that which prevailed while only the Fort Wayne outlet was in operation.

MICHIGAN

1 MASON
2 LAKE
3 OSCEOLA
4 CLARE
5 GLADWIN
6 ARENAC
7 HURON
8 BAY
9 MIDLAND
10 ISABELLA
11 MECOSTA
12 NEWAYGO
13 OCEANA
14 MUSKEGON
15 MONTCALM
16 GRATIOT
17 SAGINAW
18 TUSCOLA
19 SANILAC
20 ST CLAIR
21 LAPEER
22 GENESEE
23 SHIAWASSEE
24 CLINTON
25 IONIA
26 KENT
27 OTTAWA
28 ALLEGAN
29 BARRY
30 EATON
31 INGHAM
32 LIVINGSTON
33 OAKLAND
34 MACOMB
35 WAYNE
36 WASHTENAW
37 JACKSON
38 CALHOUN
39 KALAMAZOO
40 VAN BUREN
41 BERRIEN
42 CASS
43 ST.JOSEPH
44 BRANCH
45 HILLSDALE
46 LENAWEE
47 MONROE

INDIANA

1 LAPORTE
2 ST.JOSEPH
3 ELKHART
4 LAGRANGE
5 STEUBEN
6 DEKALB
7 NOBLE
8 KOSCIUSKO
9 MARSHALL
10 STARKE
11 PULASKI
12 FULTON
13 WHITLEY
14 ALLEN
15 ADAMS
16 WELLS
17 HUNTINGTON
18 WABASH
19 MIAMI
20 CASS
21 CARROLL
22 HOWARD
23 GRANT
24 BLACKFORD
25 JAY
26 RANDOLPH
27 DELAWARE
28 MADISON
29 TIPTON
30 CLINTON
31 BOONE
32 HAMILTON
33 HENRY
34 WAYNE
35 HANCOCK
36 MARION
37 HENDRICKS
38 MORGAN
39 JOHNSON
40 SHELBY
41 RUSH
42 FAYETTE
43 UNION
44 FRANKLIN
45 DECATUR
46 BARTHOLOMEW
47 BROWN
48 JACKSON
49 JENNINGS
50 RIPLEY
51 DEARBORN
52 SWITZERLAND
53 JEFFERSON
54 SCOTT
55 WASHINGTON
56 CLARK
57 FLOYD
58 HARRISON

OHIO

1 WILLIAMS
2 FULTON
3 LUCAS
4 OTTAWA
5 LAKE
6 ASHTABULA
7 TRUMBULL
8 GEAUGA
9 CUYAHOGA
10 LORAIN
11 ERIE
12 SANDUSKY
13 WOOD
14 HENRY
15 DEFIANCE
16 PAULDING
17 PUTNAM
18 HANCOCK
19 SENECA
20 HURON
21 MEDINA
22 SUMMIT
23 PORTAGE
24 MAHONING
25 COLUMBIANA
26 STARK
27 WAYNE
28 ASHLAND
29 RICHLAND
30 CRAWFORD
31 WYANDOT
32 ALLEN
33 VAN WERT
34 MERCER
35 AUGLAIZE
36 HARDIN
37 MARION
38 MORROW
39 KNOX
40 HOLMES
41 COSHOCTON
42 TUSCARAWAS
43 CARROLL
44 HARRISON
45 JEFFERSON
46 BELMONT
47 GUERNSEY
48 MUSKINGUM
49 LICKING
50 DELAWARE
51 UNION
52 LOGAN
53 SHELBY
54 DARKE
55 MIAMI
56 CHAMPAIGN
57 CLARK
58 MADISON
59 FRANKLIN
60 PICKAWAY
61 FAIRFIELD
62 PERRY
63 MORGAN
64 NOBLE
65 MONROE
66 WASHINGTON
67 ATHENS
68 HOCKING
69 VINTON
70 ROSS
71 FAYETTE
72 GREENE
73 MONTGOMERY
74 PREBLE
75 BUTLER
76 WARREN
77 CLINTON
78 HIGHLAND
79 PIKE
80 JACKSON
81 MEIGS
82 GALLIA
83 LAWRENCE
84 SCIOTO
85 ADAMS
86 BROWN
87 CLERMONT
88 HAMILTON

KENTUCKY

1 BOONE
2 KENTON
3 CAMPBELL
4 GREENUP
5 LEWIS
6 MASON
7 BRACKEN
8 PENDLETON
9 GRANT
10 GALLATIN
11 CARROLL
12 TRIMBLE
13 OLDHAM
14 HENRY
15 OWEN
16 HARRISON
17 ROBERTSON
18 FLEMING
19 CARTER
20 BOYD
21 LAWRENCE
22 ELLIOTT
23 ROWAN
24 BATH
25 NICHOLAS
26 BOURBON
27 SCOTT
28 FRANKLIN
29 SHELBY
30 JEFFERSON
31 BULLITT
32 SPENCER
33 ANDERSON
34 WOODFORD
35 FAYETTE
36 CLARK
37 MONTGOMERY

NEW YORK

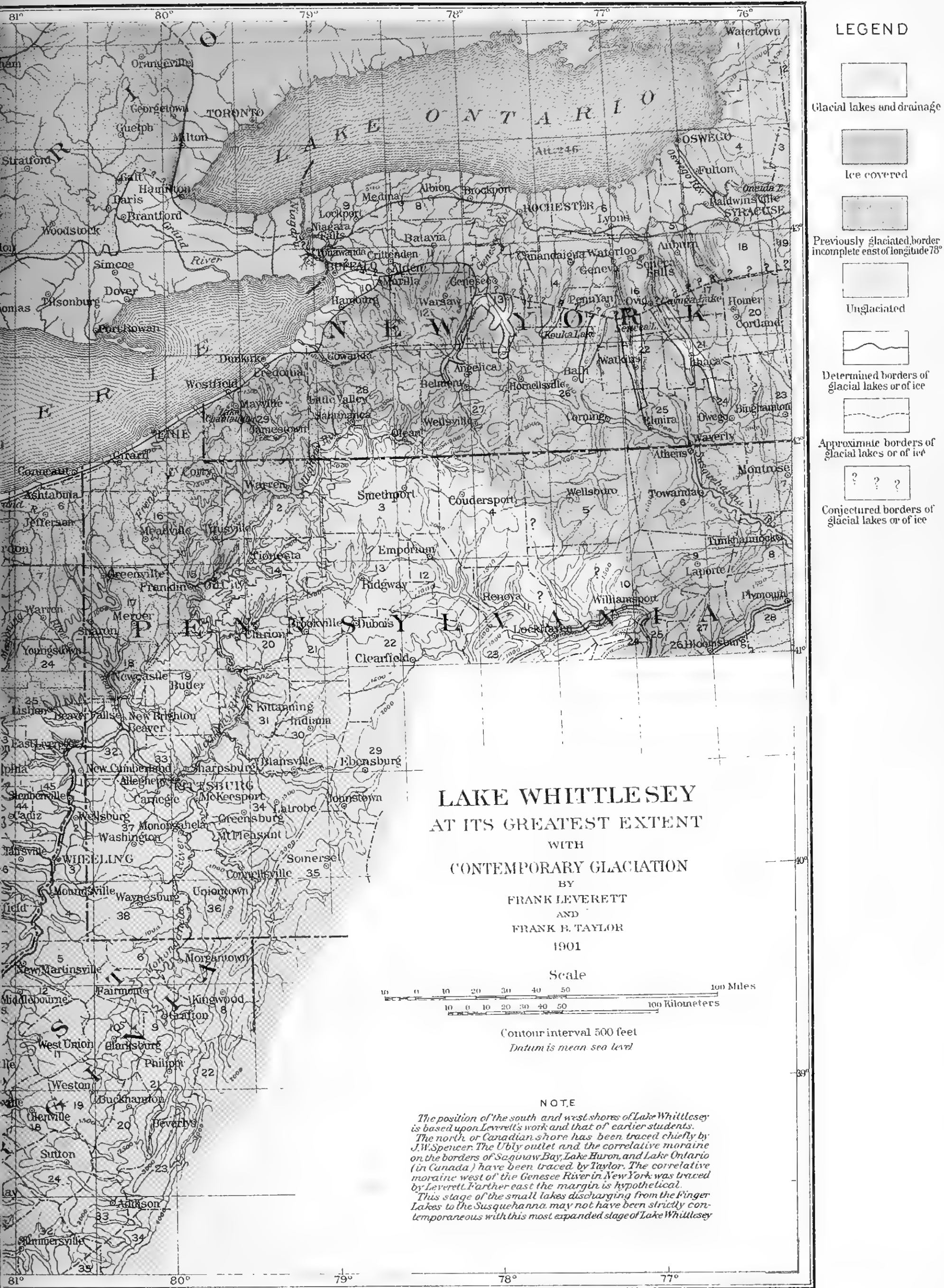
1 JEFFERSON
2 LEWIS
3 ONEIDA
4 OSWEGO
5 CAYUGA
6 WAYNE
7 MONROE
8 ORLEANS
9 NIAGARA
10 ERIE
11 GENESEE
12 WYOMING
13 LIVINGSTON
14 ONTARIO
15 YATES
16 SENECA
17 ONONDAGA
18 MADISON
19 CHENANGO
20 CORTLAND
21 TOMPKINS
22 SCHUYLER
23 BROOME
24 TIOGA
25 CHEMUNG
26 STEUBEN
27 ALLEGANY
28 CATTARAUGUS
29 CHAUTAUQUA

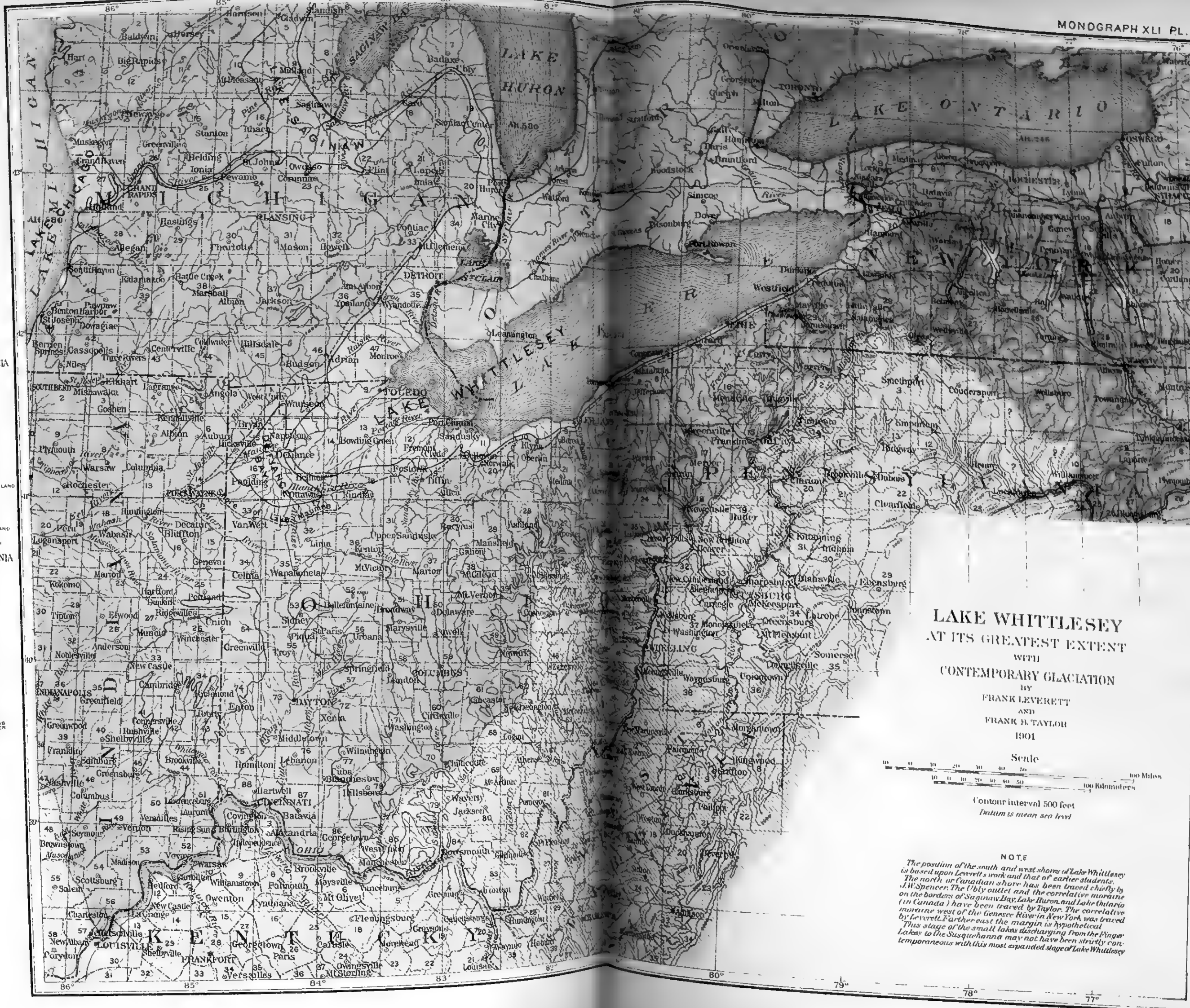
PENNSYLVANIA

1 ERIE
2 WARREN
3 MC KEAN
4 POTTER
5 TIOGA
6 BRADFORD
7 SUSQUEHANNA
8 WYOMING
9 SULLIVAN
10 LYCOMING
11 CLINTON
12 CAMERON
13 ELK
14 FOREST
15 VENANGO
16 CRAWFORD
17 MERCER
18 LAWRENCE
19 BUTLER
20 CLARION
21 JEFFERSON
22 CLEARFIELD
23 CENTER
24 UNION
25 NORTHUMBERLAND
26 MONTOUR
27 COLUMBIA
28 LUZERNE
29 CAMBRIA
30 INDIANA
31 ARMSTRONG
32 BEAVER
33 ALLEGHENY
34 WESTMORELAND
35 SOMERSET
36 FAYETTE
37 WASHINGTON
38 GREENE

WEST VIRGINIA

1 HANCOCK
2 BROOKE
3 OHIO
4 MARSHALL
5 WETZEL
6 MONONGALIA
7 MARION
8 PRESTON
9 TAYLOR
10 HARRISON
11 DODDRIDGE
12 TYLER
13 RITCHIE
14 PLEASANTS
15 WOOD
16 WIRT
17 CALHOUN
18 GILMER
19 LEWIS
20 UPSHUR
21 BARBOUR
22 TUCKER
23 RANDOLPH
24 BRAXTON
25 ROANE
26 JACKSON
27 MASON
28 CABELL
29 PUTNAM
30 KANAWHA
31 CLAY
32 NICHOLAS
33 WEBSTER
34 POCAHONTAS
35 GREENBRIER
36 FAYETTE
37 BOONE
38 LINCOLN
39 WAYNE


LEGEND
Glacial lakes and drainage
Ice covered
Previously glaciated border incomplete east of longitude 78°
Unglaciated
Determined borders of glacial lakes or of ice
Approximate borders of glacial lakes or of ice
Conjectured borders of glacial lakes or of ice
LAKE WHITTLESEY
AT ITS GREATEST EXTENT
WITH
CONTEMPORARY GLACIATION
BY
FRANK LEVERETT
AND
FRANK B. TAYLOR
1901
Scale
100 Miles
100 Kilometers
Contour interval 500 feet
Datum is mean sea level
NOTE
The position of the south and west shores of Lake Whittlesey is based upon Leverett's work and that of earlier students.
The north or Canadian shore has been traced chiefly by J.W. Spencer. The Ubly outlet and the correlative moraine on the borders of Saginaw Bay, Lake Huron, and Lake Ontario (in Canada) have been traced by Taylor. The correlative moraine west of the Genesee River in New York was traced by Leverett. Farther east the margin is hypothetical.
This stage of the small lakes discharging from the Finger Lakes to the Susquehanna may not have been strictly contemporaneous with this most expanded stage of Lake Whittlesey
LAKE ONTARIO
NEW YORK
PENNSYLVANIA
TORONTO
ROCHESTER
OSWEGO
SYRACUSE
BUFFALO
ERIE
Alt. 246
Dunkirk
Jamestown
Olean
Elmira
Binghamton
Williamsport
Wheeling
Morgantown



MICHIGAN

KENTUCKY

NEW YORK

INDIANA

PENNSYLVANIA

OHIO

WEST VIRGINIA

LEGEND

Glacial lakes and drainage

Ice covered

Previously glaciated border (incomplete east of longitude 75°)

Unglaciated

Determined borders of glacial lakes or of ice

Approximate borders of glacial lakes or of ice

Conjectured borders of glacial lakes or of ice

JULIUS BIEN & CO. LITH. N.Y.

CHAPTER XV.

THE GLACIAL LAKE WHITTLESEY.

INTRODUCTORY.

The name Lake Whittlesey was suggested by Taylor in 1897,[1] for the lake which formed the Belmore beach of the Erie-Huron basin. He also discovered the lake's outlet across the "thumb" of Michigan and named it the Tyre-Ubly outlet.[2] He has since shortened the name to Ubly outlet. The Belmore beach was named and partially described by N. H. Winchell in 1872,[3] but parts of it had been mapped many years earlier. Bela Hubbard had traced it for more than 60 miles in southeastern Michigan at the time his report to Douglas Houghton was prepared in 1840,[4] and he mentioned its presence at Plymouth, York, and Ridgeway, Mich. A map in the same report, drawn by S. W. Higgins, shows the position of the beach in Wayne County, Mich. In a report published the following year,[5] Hubbard called attention to the continuation of the mapping of this beach across Macomb into St. Clair County. At a still earlier date Whittlesey made reference to the lake ridges south of Lake Erie in an official report published for the First Ohio Geological Survey,[6] but it is not certain that he had attempted to trace their courses at that time. A few years later he had traced two or more of the beaches from Erie, Pa., westward past Cleveland to the Vermilion River, and noted that from that point they bear farther inland.[7] This tracing seems to have included the Belmore beach. He found difficulty in accounting for the beaches, inasmuch as they occur above

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[1] Bull. Geol. Soc. America, Vol. VIII, 1897, p. 39.

[2] Loc. cit., pp. 40–41.

[3] Proc. Am. Ass. Adv. Sci., Vol. XXI, 1872, pp. 177–179.

[4] Third Ann. Rept. of Dr. Douglas Houghton, pp. 102–111. Published as house document No. 8, Detroit, 1840.

[5] House document No. 27, pp. 120–122, Detroit, 1841.

[6] Second Ann. Rept. Geol. Surv. of Ohio, 1838, p. 55.

[7] Notes upon the drift and alluvium of Ohio and the West: Am. Jour. Sci., 2d series, Vol. V, 1848, pp. 205–217. On the natural terraces and ridges of the country bordering Lake Erie: Am. Jour. Sci., 2d series, Vol. X, 1850, pp. 31–39. On the fresh-water glacial drift of the Northwestern States: Smithsonian Contrib., Vol. XV, 1867, 32 pages.

the level of the ridge cut through by the Niagara River near Buffalo, and also above the divide at the head of Lake Michigan, for at that time the relation of the lakes to the ice sheet was not even dimly conceived.

The Belmore beach is the "third beach" of Gilbert's series in the Maumee basin,[1] and is the same to which Spencer applied the name Ridgeway in Michigan.[2] The name Belmore, however, has priority, and has also the advantage of being less liable to lead to confusion than Ridgeway. The latter name has been applied to at least thirteen towns in the United States, and there is a Ridgeway in each of the four States bordering Lake Erie. As a further disadvantage the name Ridgeway is applied to a town in New York that stands on a different beach from the one under discussion.

The course of the Belmore beach had been mapped throughout much of its extent from southern Michigan through Ohio and northwestern Pennsylvania to southwestern New York before the writer began investigations. Attention, therefore, has been given chiefly to such portions as others had not attempted. The extent of the beach in southwestern New York was worked out in company with F. B. Taylor. Taylor also assisted in tracing the beach around the part of Defiance Bay north of the Maumee River.

UBLY OUTLET.

This outlet for Lake Whittlesey having been discovered and brought to notice by Taylor[3] and no opportunity having been afforded the writer to examine the outlet, Taylor's discussion, both of the outlet and of neighboring parts of the Belmore beach, is here presented:

> The most northerly point of Spencer's tracing [of the Belmore beach] is 2 miles east of Emmet, where the altitude is 770 feet. From this point it was followed north and then east past Spring Hill, 2 miles northeast of Avoca, where its altitude is about the same. It is a strong and well-formed beach and is easily followed to this point. At Spring Hill it culminates in a great blunt spit of gravel compounded of many beach ridges laid up one against the other. The head of the spit projects toward the northeast, is about 40 rods wide, and at its front stands about 15 feet above the flats to the east and 10 feet above those to the northwest. Two more fragments of this beach were found within 3 miles northwest from the spit, both gravelly projecting points. Mr. Gilbert also traced this beach from Emmet to Spring Hill. North of the spit there is a stretch of 10 miles or more of very flat land on which no beach was seen. Four miles west of Crosswell a faint shore line was found along the base of high

[1] Geology of Ohio, Vol. I, 1873, pp. 554, 569–570.
[2] Am. Jour. Sci., 3d series, Vol. XLI, 1891, pp. 204–208.
[3] Bull. Geol. Soc. America, Vol. VIII, 1897, pp. 39–46.

ground about a quarter of a mile north of the corner at Buel; altitude about 780 feet. Again, on the east slope of a kame-ridge, 3¼ miles west of Applegate, is perhaps the best developed beach seen in Black River Valley north of Spring Hill. Its altitude is about 770 feet. It is a low ridge of fine sandy gravel facing east over flats 30 to 40 feet lower and 3 to 5 miles wide. At a point 2½ miles west and 1 mile north of Applegate the same faint beach was found at the same height, and it was found again on a slope 6 miles west and 1 south. There is also a very faint mark at the same height on the north slope of this kame-ridge, facing north over Elk Creek and the great Black River Swamp. * * * Along Black River from Carsonville southward toward Applegate there is an extensive gravel plain 30 to 35 feet below the beach. At the cemetery, 2 miles south of Carsonville, the valley at the head of the beach is narrowed somewhat where it passes between the high moraine east of Black River and the kame-ridge which lies along the south side of Elk Creek. From the narrows the Black River Swamp extends northward over the summit to Cass River at Tyre and Ubly, a distance of 30 miles. In this stretch no beach or certain water mark was found. The Belmore beach had, therefore, to be given up without having definitely established its connection by continuous tracing with any outlet channel. The faint fragments near Buel and Applegate are the only ones found north of Spring Hill that could be supposed to belong to this beach. Nevertheless it is clearly the correlative of the Tyre-Ubly outlet described next below.

The Black River Swamp passes over the col to the head of Cass River, about 2 miles east of Ubly. A low gravel bank on the west side and midchannel bars on the crossing east of Ubly indicate that the water was at least 10 or 12 feet deep on the col. This is now about 790 feet above sea level. The old water level is therefore about 800 feet. On this crossing the swamp is nearly a mile and a half wide. The main channel passes northwest from the col to a point about a mile north of Ubly, where it becomes much narrower, scarcely more than a half mile, and makes a sharp bend to the southwest, in which direction it continues 17 miles to its terminus, about a mile east of Cass City. Ubly is on the floor of the channel, on the east side, 1 mile south of the bend. Two other smaller branch outlet channels cross cols about 2 miles east and southeast of Tyre. At this place they unite and pass thence as one channel close to Ubly on the south, and join the Ubly channel at a point a mile or more below the latter place. Tyre is about 4 miles southeast of Ubly and is also on the channel floor. Both channels possess distinct characters of water courses. The Tyre channel is a bowldery swamp for some distance above the town, and at the station there is scarcely any covering over the underlying sandstone. The strata are bare in many places and the thin soil is very gravelly and stony. The Ubly channel is floored almost entirely with beds of gravel above the junction of the branches. Bowlders are numerous in some places, as on the east side a little below the bend, 1 mile north of Ubly. The gravels were observed at several places to be at least 4 or 5 feet deep. Below the bend the width of the channel increases to three-fourths of a mile to a mile, and keeps this width to Cass City. From the junction the floor of the channel is covered with great numbers of bowlders for the most of the distance down to its lower end. The bowldery floor, nearly a mile wide, is well displayed at Holbrook, about halfway down from Ubly. The floor a mile and a half east of Cass City has an altitude of about 730 feet. In its present attitude the floor descends

about 70 feet from the col east of Ubly to Cass City, about 22 miles, but the descent of the water surface was probably somewhat less.

Cass City is built upon a gravel plain about 2 miles long east and west and nearly a mile wide, which from its position strongly suggests that it may be a delta of the outlet of Lake Whittlesey. Its top level is about 750 feet above sea level or 20 to 25 feet above the old channel bottom. There appeared to be a fragment of the same plain on the south side of the river also, as though the original deposit had been cut in two.

The contemporary position of the ice front with respect to this outlet is very clearly marked. The last land-laid moraine of the Huron lobe of the ice sheet lies close to the east side of Black River all the way northward from a point 6 or 8 miles northwest of Port Huron. Where the Black River Swamp is wide the main crest of the moraine is sometimes 4 or 5 miles from the river, but it is usually half that distance or less. The moraine is usually dual or triple in form, with 2 or 3 crests or ridges running roughly parallel half a mile to a mile and a half apart, the western one being the highest. Toward Ubly the moraine trends northwest, and at a point about 3 miles northeast of Ubly it meets the contemporary moraine of the Saginaw lobe coming from the southwest, and the two form a sharply defined angle of 75°. The high ridges of the two moraines do not unite, but are cleft just in the angle. A small brook, the headwaters of Willow River, drains a part of the gravelly channel bed at the extreme north angle of the bend and carries its waters away north through the narrow gap to Lake Huron, near Grindstone City. This cleft probably marks the entrance of a small glacial tributary to the great outlet river flowing from the ice sheet when its front rested close by on the main moraine. The bend of the channel is exactly in the angle of the two moraines, but the narrowest point is half a mile farther west. The crest of the Saginaw moraine from the bend to Cass City is 80 to 100 feet or more above the channel floor, and the channel runs close along its foot all the way. The inner angle of the bend is held by a high, steep hill of drift, with many bowlders. It is the northwest end of a lower ridge, which seems to belong to the eastern or Huron lobe of the ice sheet. This hill has been cut away to some extent on its north and west sides, leaving many bowlders at its base. The base of the moraine opposite is also quite steep, apparently from the same cause. The hill in the angle evidently once extended a little farther to the northwest. Southwest of Tyre morainic ridges, mostly of moderate height, trend in a general east-to-west course. One of these lying next south of the Tyre branch is high at its west end, like the one north of Ubly, and appears at one time to have stood in much the same relation to the river. It stands in the angle where the Tyre channel turns southwest into the main channel.

The Tyre branch was apparently opened before the Ubly, and the former served as an outlet, while the ice front of the Huron lobe still rested on the morainic ridge which now separates the two branches. A later retreat of a mile or two by this lobe left an open space close along the ice front in the new position, and this became the Ubly branch. After the Ubly branch opened the volume of discharge by the Tyre channel must have been largely decreased, but the level of the lake was probably not lowered much, for the heads of both branches are nearly at the same level. Judging from the comparative magnitude of the moraine between the channels and the later

main moraine, it seems certain that the early activity of the Tyre channel must have been quite short, as compared with the later period of their combined activity. In no other instance known to the writer is the relation of a great ice dam and the outlet of the waters which it retained so close or so clearly and unmistakably shown. Ten miles north of Ubly the surface of the thumb begins a gradual descent of 200 feet to Lake Huron. The circumstances in this case are such that there can be no possible doubt as to the place of the ice front while this outlet was active. It was not over a mile or two from Ubly, and the outlet river from the col to Cass City flowed close along the foot of the ice front. This position of the outlet was a natural consequence of the fact that the ice front was retreating northward down a slope, which happened to be the lowest part of the rim of the lake. For this reason the outlet hugged the receding ice front, and changed its place as fast as lower points of escape were uncovered.

By following the course of the Saginaw moraine to the southwest, curving back to the north on the west side of the valley, and the course of the Port Huron moraine to the southeast, curving back to the northeast in Ontario, we find the exact position of the great ice dam in the basins of Saginaw Bay and the south arm of Lake Huron. It only remains to locate the contemporary ice front in the eastern part of the Erie basin to know the exact boundaries of Lake Whittlesey.

THE BELMORE BEACH FROM THE UBLY OUTLET TO THE MAUMEE RIVER.

The writer has examined the beach no farther north than the vicinity of Romeo, Mich., but from notes furnished by Taylor its course can be outlined from Emmet to this point. From Romeo southward the writer has given it sufficient attention to outline much of its course from his own notes, but has received from W. H. Sherzer, of the Michigan geological survey, notes concerning its course in Washtenaw County.

DISTRIBUTION.

From Emmet the course is southward to the vicinity of Lenox, in northeastern Macomb County. It there curves around to a course north of west past Armada to a point about 2 miles northeast of Romeo, where it swings southward and leads through Washington to Clinton River just below Rochester. The village of Rochester stands upon a delta which was formed in connection with this beach. The beach continues in a course west of south for about 12 miles from Rochester, passing $1\frac{1}{2}$ miles southeast of Birmingham. It there curves abruptly westward, forming an interesting series of hooks in its curving portion and crosses to the west side of East Rouge River about 2 miles southwest of Birmingham. From this point its course is southwestward through Farmington to Plymouth, where it crosses

West Rouge River. A complicated series of bars was formed on the delta of this system opposite Plymouth and extends the beach southward a half mile or more beyond the north end of the ridge on the west side of the stream. From Plymouth the course is west of south to Huron River about 2 miles below Ypsilanti. This river has a broad terrace at Ypsilanti which harmonizes in level with the beach and was apparently formed in connection with it. The beach continues in a southwestward course to Saline River at York and thence past Ridgeway to Raisin River, a mile west of Lenawee Junction. From this stream its course is southward 5 or 6 miles, then southwestward about 3 miles to Black Creek near Jasper. It then bears southeastward into Ohio, entering that State about 3 miles west of Metamora.

From the Ohio-Michigan line the beach continues southeastward only 3 or 4 miles. It then curves around to a southwest course and leads through Ai and Delta to Ridgeville Corners, where the course changes to the south and the beach comes to the Maumee River about 4 miles east of Defiance. Throughout its course in Michigan it lies east of the Defiance moraine, but in northern Ohio it turns toward the moraine and rises to the crest near Ridgeville, from which point it follows the crest to the Maumee River.

DESCRIPTION OF THE BEACH.

The beach presents remarkable uniformity on the western shore of the lake. It is commonly a low bank, 4 to 8 feet high, with very gradual slopes which are coated with gravel. The gravel extends up to the top of the bank and gives it a relief of a foot or two above the plain back of it. There are very few places in which the beach differs markedly from this type form, and the gaps are remarkably few and small. Although a weak feature so far as dimensions are concerned, its continuity and its regularity are such as to arrest the attention of all who cross it.

The deltas formed where streams entered are usually of gravelly constitution and are as strong on this west shore as in any part of the lake border, the rate of fall in the streams being rapid and much gravelly material being formed along their courses.

The deltas are usually best developed back of the beach, but in places they extend out some distance into the old lake bottom. A conspicuous instance of such an extension appears along Huron River. Sherzer has

found a fine gravelly deposit spread out in fan shape to a distance of fully 3 miles below the point where the river crosses the beach. The distance to which this deposit reaches seems greater than the limits of transportation by the river currents. It is possible, however, that the material was extended lakeward in connection with the lowering of the lake to the next beach.

VARIATIONS IN ALTITUDE.

This western shore of Lake Whittlesey appears to be nearly horizontal from the Maumee River northward to Birmingham, Mich., or about to latitude 42° 30′. The altitude of the crest of the ridge is usually between 735 and 740 feet. Northward from latitude 42° 30′ the rise is very gradual as far as Armada and Lenox (about latitude 42° 50′), the altitude being between 745 and 750 feet at those points. But at latitude 43°, near Emmet, the beach is reported by Spencer to be 770 feet, and at the head of the Ubly outlet, 40 miles farther north, the old water level was found by Taylor to be near the 800-foot contour. The exceptionally rapid rise between Emmet and Lenox may not be entirely due to uplift. Taylor's observations indicate that the ice sheet stood at that time only a few miles east from Emmet. Ice attraction may therefore be responsible for part of the rise shown by the beach. It should also be borne in mind that the levels here given are from railway surveys, and a comparison of the different surveys shows differences amounting sometimes to several feet in the altitude of a given point.

THE SHORE OF DEFIANCE BAY.

In his description of the Belmore beach in northwestern Ohio, Gilbert, after tracing the beach to the Maumee Valley, stated that a landlocked bay west of it stretched up the Maumee Valley,[1] but he gave it no name and seems not to have determined its full limits, nor does he mention the occurrence of a beach along its shore. This beach apparently was not definitely traced until 1899, when the portion north of the Maumee was worked out by the writer in company with F. B. Taylor, and the portion south by the writer alone. The name Defiance Bay was agreed upon by Taylor and the writer as suitable for this extension of Lake Whittlesey, for the double reason that the city of Defiance stands near its deepest portion and the Defiance moraine separated it from the remainder of the lake.

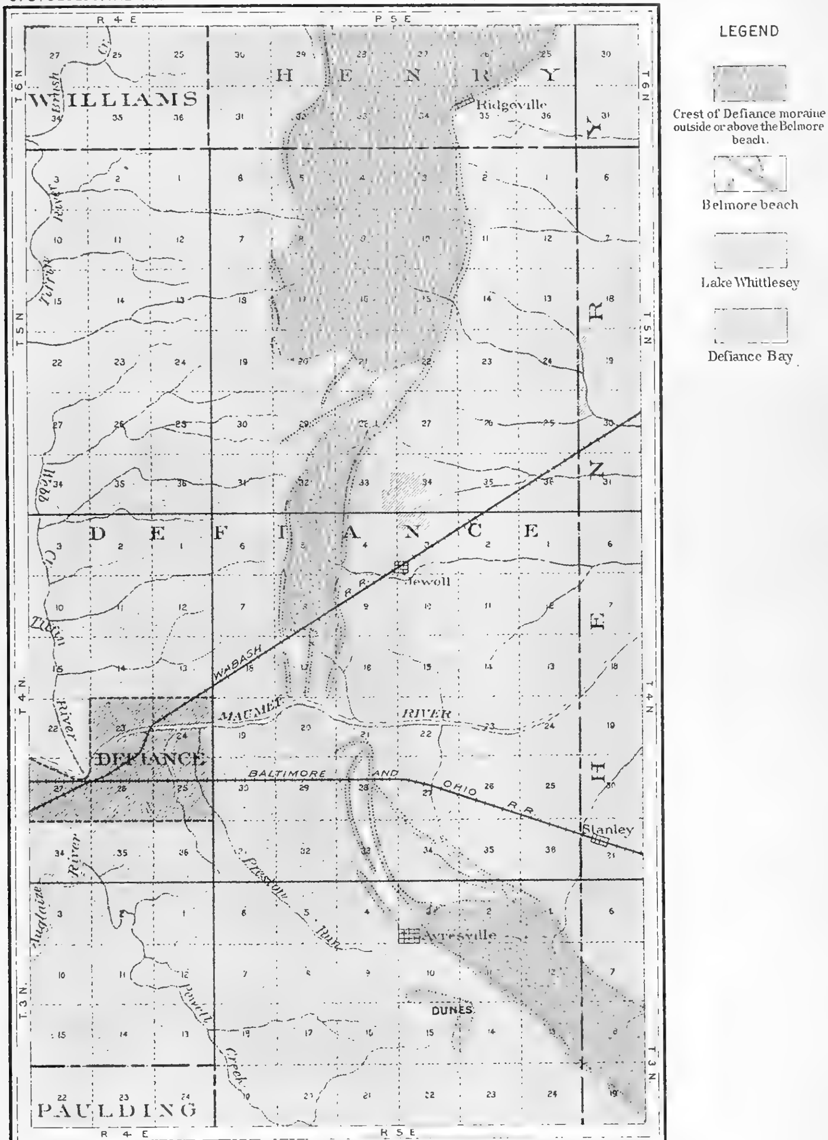
[1] Geology of Ohio, Vol. I, 1873, p. 554.

From the Maumee River east of Defiance the beach which was formed on the east side of Defiance Bay follows nearly the crest of the Defiance moraine for several miles to the north and south of the river, as indicated on the accompanying map, Pl. XXIV. It is not so regular and continuous as the beach formed by the lake in that vicinity, but its average strength is about as great. It was favorably situated for receiving the heavy waves raised by winds from the west, and this seems to account for its exceptional strength in that part of its course. It is very regular and continuous for 4 miles north of the river, and differs but little from the lake beach to the east. It shows clearly by its bedding as well as its form that it was built by a body of water standing west of it. It rises about 6 feet above the western base and but 2 or 3 feet above the eastern. Upon entering Adams Township it soon breaks up into disjointed ridges, which are distributed over a space a mile or more in width. It then becomes regular for a few miles, in passing across western Henry County.

In Henry County the lake beach turns northeastward, while the beach of the bay continues north. The crest of the Defiance moraine soon rises above the level of the beaches, and they then follow the slopes. The beach of Defiance Bay crosses Brush Creek south of Archbold and continues northward through the west part of that village, passing just west of the public-school building. It then turns east of north, but becomes very faint within 3 or 4 miles, and finally merges into a sandy plain that lies between the Defiance moraine and Bean Creek Valley within 6 or 8 miles of the Ohio-Michigan line.

West of Bean Creek a well-defined beach was found that crosses from Fulton into Williams County about 3 miles east of West Unity, and bears southwestward across Brady Township at a distance of 1 to 2 miles west from Bean Creek. It seems to be at about the level of the Belmore beach, but it is so much stronger than the remainder of the beach as to raise a suspicion that it was not produced solely by the waves of Defiance Bay. However, no other agency can as yet be suggested. Between this bank and the Maumee beach at West Unity there is a tract of sharply undulating drift, which dies out in a plain. The cut bank also loses strength and becomes very faint in southwestern Brady Township.

Upon the disappearance of the cut bank a strip of sandy gravel sets in to mark the continuation of the shore. This in places carries low ridges 2 to 4 feet high, but has generally a nearly plane surface. The best defined



JULIUS BIEN & CO. LITH. N.Y.

MAP OF THE BELMORE BEACH
ON THE
BORDERS OF LAKE WHITTLESEY AND DEFIANCE BAY
NEAR DEFIANCE, OHIO
BY FRANK LEVERETT
1901

Scale
1 0 1 2 3 4 5 MILES
1 0 1 2 3 4 5 KILOMETERS

ridge noted crosses the Lake Shore and Michigan Southern Railway $3\frac{1}{2}$ miles east of Bryan, or about a mile west of the Springfield and Pulaski township line. This ridge continues from this point southwestward for about 2 miles to the valley of Beaver Creek, 2 miles directly east of Bryan, beyond which it is not so definitely developed. This western shore of Defiance Bay from the latitude of Bryan southward presents only patches of sand and occasional slight traces of wave cutting to show its position. The plain on which it was formed descends so gradually toward the east that there was scarcely sufficient depth of water to afford strong wave action.

The delta of the Maumee is also ill defined, and apparently was spread out as a thin sandy deposit extending from near Fairport, Ind., eastward about to Cecil, Ohio, a distance by direct line of nearly 20 miles. At Cecil the plain bordering the Maumee stands only about 15 feet below the level of the beach and at Fairport scarcely 10 feet above it. The slope averages, therefore, but little more than 1 foot per mile.

A peculiarity of drainage east of Fairport also seems to indicate that the delta sets in near that village. Sixmile Creek, a tributary of Auglaize River, leads away from near the south bluff of Maumee River like a distributary of a delta, and it is found that a sag or shallow channel connects the river with the head of the creek.

South from Maumee River the first suggestion of the position of the west shore of Defiance Bay was found near Flat Rock Creek, northeast of Payne, Ohio. A low ridge strewn with bowlders appears about 3 miles north of Payne, near the corners of sections 14, 15, 22, and 23, Harrison Township, and leads southeastward through sections 23, 24, and 25 to Flat Rock Creek, near the line of Harrison and Paulding townships, and thence to Worstville station, on the Nickel Plate Railroad. From Worstville it bears eastward along the south side of the railroad to Briceton, and there takes a course north of east and is traceable as far as section 20, Jackson Township. This ridge has a clay surface, but is known to contain some gravel, there being a pit opened in it about 2 miles northeast of Briceton. Some hesitancy is felt in referring to this as a shore feature, though it occurs at about the level of the Belmore beach and its size is no greater than the usual size of that beach. It looks quite as much like a low glacial ridge, and the large number of bowlders which it carries seems to bear out this interpretation. It stands, therefore, as a rather questionable shore line.

The level at which the Belmore beach should occur was crossed at

many points on the west border of the bay southeastward from the end of this ridge, but evidences of strong wave action were not discovered, and but few places were found that even suggested a shore. It is possible that this part of the bay was occupied by rushes or other vegetation which protected the shore from wave action. The bay probably extended up the Auglaize River Valley to within 3 or 4 miles of Fort Jennings and up the Ottawa River beyond Kalida. There are low, sandy ridges setting in about 2 miles southeast of Kalida and passing eastward into northwestern Pleasant Township, which are thought to have been formed along or near the shore of this bay. The bay probably extended up Blanchard River 2 or 3 miles beyond Ottawa, but its depth was scarcely 10 feet at the site of that city. North and also northwest of the city there are low, sandy ridges which were probably formed by the bay. A definite beach sets in about 4 miles north of Ottawa near Brickner post-office and leads northward along or near the Napoleon wagon road to the Nickel Plate Railroad. It is there near the border of the Defiance moraine, and the Maumee beach lies but a short distance northeast of it. It is much weaker than the Maumee beach, being a ridge only 1½ to 3 feet in height and a few yards in width.

The course of this beach was not definitely located for 3 or 4 miles northwest from where it crosses the Nickel Plate Railroad. A faint sand ridge was found on the crest of the Defiance moraine in the north part of section 17 and south part of section 8, Liberty Township, which probably belongs to this beach. In the northwest part of Liberty Township a definite beach was found which leads from the north part of section 7 northwestward into section 1, Palmer Township. It is 3 to 6 feet high and is composed mainly of gravel. Its form is much like that of the shore of Lake Whittlesey to the north, but it faces southwest and was evidently formed from that direction. From this point northwestward to Pleasant Bend, short gravelly ridges appear at frequent intervals and there is said to have been a well-defined gravel ridge in the village, passing near the Toledo, St. Louis and Kansas City Railroad station, but it has been removed for road ballast. Gravel has also been obtained from this ridge on the farm of John Burkhardt, 2 miles southeast of Pleasant Bend.

Near the line of Henry and Defiance counties, 2 miles northwest of Pleasant Bend, a strong beach sets in which leads northwestward past Ayersville to the Maumee Valley, 3 miles east of Defiance. The shore of

Lake Whittlesey lies only 1 to $1\frac{1}{4}$ miles north of it, and sandy ridges fill in part of the interval between the two beaches. In the part north of Ayersville the lake seems to have washed the eastern face, while the bay washed the western face of the ridge. But the lake subsequently built up a beach farther east, leaving the western ridge to be washed by the bay alone. This interpretation is based upon the bedding of the gravel as well as the form of the ridge, large gravel pits in the western ridge north of Ayersville showing clearly that the waves came in from the east. The east and west ridges became united at the north near the Baltimore and Ohio Railroad, and from the north end a hook curves around to the west and south in such manner as to suggest that a current passed into the bay from the lake. Sand dunes are not confined to the interval between the two ridges, there being a prominent range west of the west ridge 1 to 2 miles west of Ayersville. The complexity of the shore features will be seen by reference to the map (Pl. XXIV).

The altitude of the beach of Defiance Bay at Pleasant Bend is shown by the profile of the Toledo, St. Louis and Kansas City Railroad to be 742 feet, while the beach of Lake Whittlesey at New Bavaria is shown by the same railroad to be about 5 feet lower. This slight difference may prevail for some distance southeast from Pleasant Bend, for the bay beach stands very near the water parting on the moraine while the lake beach is 2 or 3 miles north of the water parting. The surface for some distance north from the crest or water parting is, however, so flat that ditching is necessary to obtain adequate drainage, and the fall can be but a very few feet between these beaches. At Archbold the Defiance Bay beach has nearly the same altitude as the Lake Shore and Michigan Southern Railway station, or about 735 feet. It is as low as the neighboring part of the lake beach. The ridge crossed by the same railway on the west side of the bay is shown by the profile to be 173 feet above Lake Erie, or very nearly 735 feet above tide.

THE SOUTH SHORE OF LAKE WHITTLESEY.

DISTRIBUTION.

From the south bluff of the Maumee River, about 3 miles east of Defiance, a well-defined beach similar to that north of the river leads southeastward to New Bavaria, thence eastward to Ridgeland, thence south of east through Belmore and Deweyville into northwestern Hancock

County. It there curves around to a course north of east and passes into Wood County near North Baltimore. About a mile north of North Baltimore it turns eastward and passes north of Bardstown and Bloomdale and leaves Wood County about 4 miles north of Fostoria. For 3 or 4 miles in the western part of Seneca County it is ill defined on account of the presence of rock hills, but near Amsden it reappears in strength and leads northeastward past Kansas about to the county line. It there curves abruptly to a southward course and runs out at a creek valley about a mile east of Kansas.

Faint traces of the shore were found near Angus and thence southeastward along an angling road to the Pan Handle Railroad which it crosses at the township line about 3 miles north of Tiffin. The beach then bears eastward near the township line to the Sandusky River, and after crossing the river takes a northeastward course, passing through Watson and about 2 miles south and east of the village of Greenspring. It passes about 2 miles east of Clyde and enters Erie County 5 or 6 miles north of Bellevue. In western Erie County a bay extended back to the north edge of Bellevue, but the border is indistinctly outlined because of the shallowness of the water and the presence of small islands to the north and east. There were also islands immediately southwest of Castalia which add to the complexity (see Pl. XXII).

At North Monroeville, about 6 miles east of Bellevue, the lake shore becomes reduced to a single definite ridge which leads southward into Huron County past Monroeville and there curves around to the east, crossing East Huron River about a mile south of the Lake Shore and Michigan Southern Railway. Its course is then northeastward through Norwalk and East Norwalk into Erie County. For several miles it lies near the Maumee beach and passes with that beach through the village of Berlin Heights. From Berlin Heights eastward to North Amherst it lies 1 to 2 miles north of the Maumee shore. From North Amherst it swings around southward to the city of Elyria. It leads into Elyria from the northwest, but leaves that city in a course north of east and, passing through Ridgeville and Dover, comes to Rocky River within a mile north of the Maumee shore. t curves around with that shore through West Cleveland and runs through the southwestern part of the city of Cleveland along Dennison avenue.

Upon crossing the Cuyahoga Valley it passes northward through the

eastern part of Cleveland into East Cleveland and thence takes a course northeastward about parallel with the shore of Lake Erie, and distant from it but 3 to 5 miles, through the northeast part of Ohio. It lies south of the Nickel Plate and the Lake Shore and Michigan Southern railways, and is within view from one or both railways from Cleveland eastward into Pennsylvania.

In Erie County, Pa., the beach continues about parallel with the shore of Lake Erie, passing through East Springfield and just north of Girard and Fairview, and leading through the southern part of the city of Erie and the northern part of the village of Northeast.

At the Pennsylvania-New York line this beach stands between the Nickel Plate and Lake Shore railways, but soon passes to the south of the Nickel Plate and leads through the southern part of Ripley and the extreme southern edge of Westfield. It passes south of the villages touched by these railways farther east, being near the base of the escarpment. It crosses the Dunkirk and Allegheny Valley Railroad about a mile east of Sheridan and Walnut Creek, within a mile of Forestville. It then swings northward to Hanover Center and there makes an abrupt turn to the east and continues in that direction to the valley of Cattaraugus Creek, which it crosses about a mile above Versailles. An extensive gravel delta known as the "Fourmile level" was formed in the Cattaraugus Valley above Versailles in connection with this lake stage.

On the east side of Cattaraugus Valley there is some complexity because of islands on the border of the lake. The most prominent extends from the Indian Council House 2 miles east of Versailles northward nearly to North Collins, a distance of 3 or 4 miles. It received the strong action of the waves and protected a narrow strip of water back of it from wave action. A bar or spit extended eastward from the north end of this island, nearly shutting off the passage back of the island, as indicated in Pl. XXV.

From North Collins the shore followed the base of an escarpment northward to Eden Center, where it swung eastward to the west fork of Eighteenmile Creek. In crossing this valley it turned northward, passing about a mile east of Eden Valley. A small island appears about 1½ miles northeast of Eden Valley, as indicated in Pl. XXV, which was separated from the mainland to the south by a narrow channel into which a prominent spit was extended from the island toward the mainland. East from this island the

shore curves around from a northeastward to a southeastward course and comes to East Eighteenmile Creek Valley near the line of Hamburg and Boston townships. It then passes northward toward Orchard Park, crossing the Hamburg moraine immediately south and east of that village. There were small islands along the south border of the moraine (see Pl. XXV).

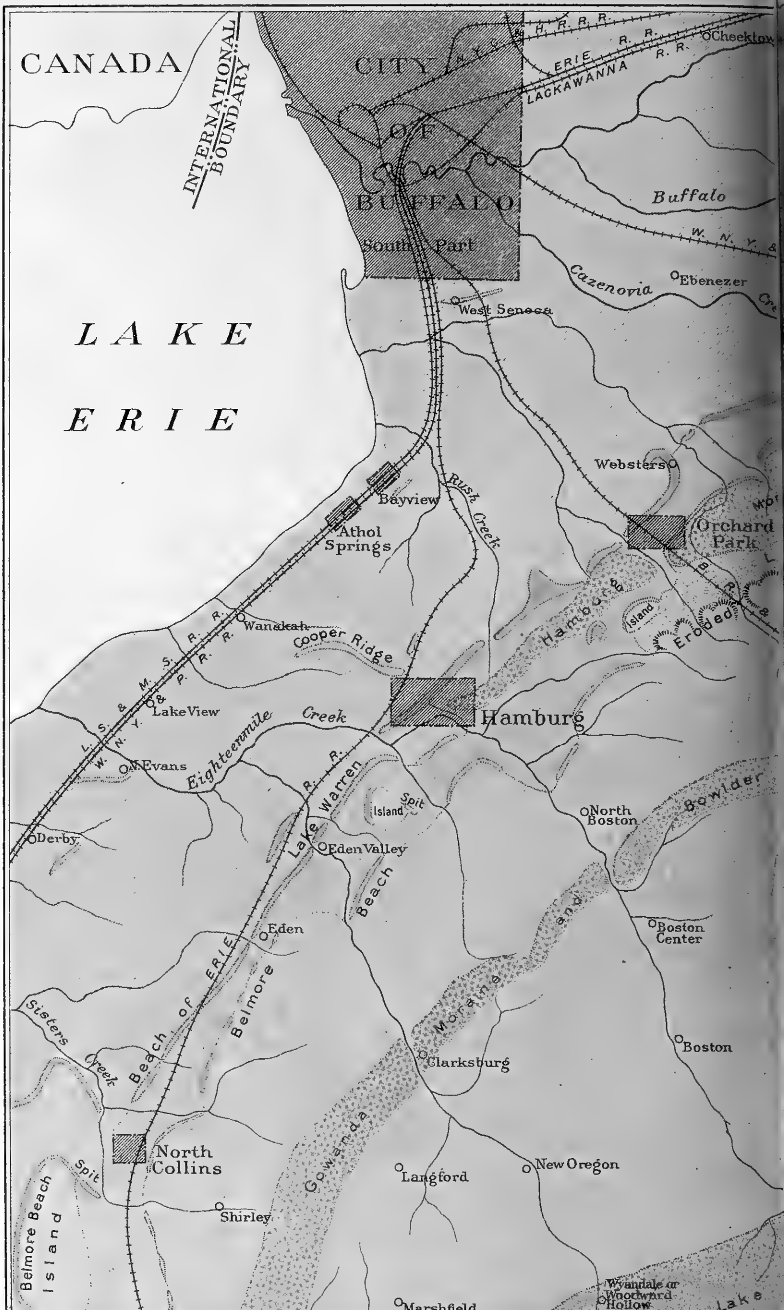
From Orchard Park the course was traced eastward by the writer in company with F. B. Taylor in the autumn of 1899, and the sinuosities of the shore shown in Pl. XXV were mapped in considerable detail. It will be observed that the beach follows the inner slope of the Hamburg moraine in a very winding course as far as the village of Marilla, where it appears to terminate. Its apparent terminus is south of the western end of the Marilla moraine, and, so far as examined, no trace of it was found on that moraine. This negative evidence, combined with the fact that the beach is very weak from the point where it crosses the Hamburg moraine eastward to Marilla, led us to conclude that the lake level had dropped before the ice sheet had withdrawn from the Marilla moraine.

VARIATIONS IN STRENGTH.

From the Maumee River southeastward as far as the Sandusky River the Belmore beach is no stronger than on the west shore of the lake, and its general appearance is quite similar to that of the west shore. The portion between Fostoria and the Sandusky River is weaker, on the whole, than any section of similar length found on the west shore of the lake, though the beach is well defined between Amsden and Kansas, where its trend is from southwest to northeast. The weak places are found either at hilly tracts or at points where the shore faced the northeast.

East of the Sandusky River the shore for about 25 miles faced the northwest, and this portion shows the effect of somewhat stronger wave action than is commonly found in the portion already described. There is usually a cut bank standing 10 or 15 feet above the plain on its inner border which is in places flanked by heavy deposits of gravel.

Among the hills of western Erie County the beach is very irregular in strength and far from continuous; but from North Monroeville south and east to Norwalk there is a regular and continuous ridge similar to that found on the west shore of the lake. Near Berlin Heights the shore is chiefly a

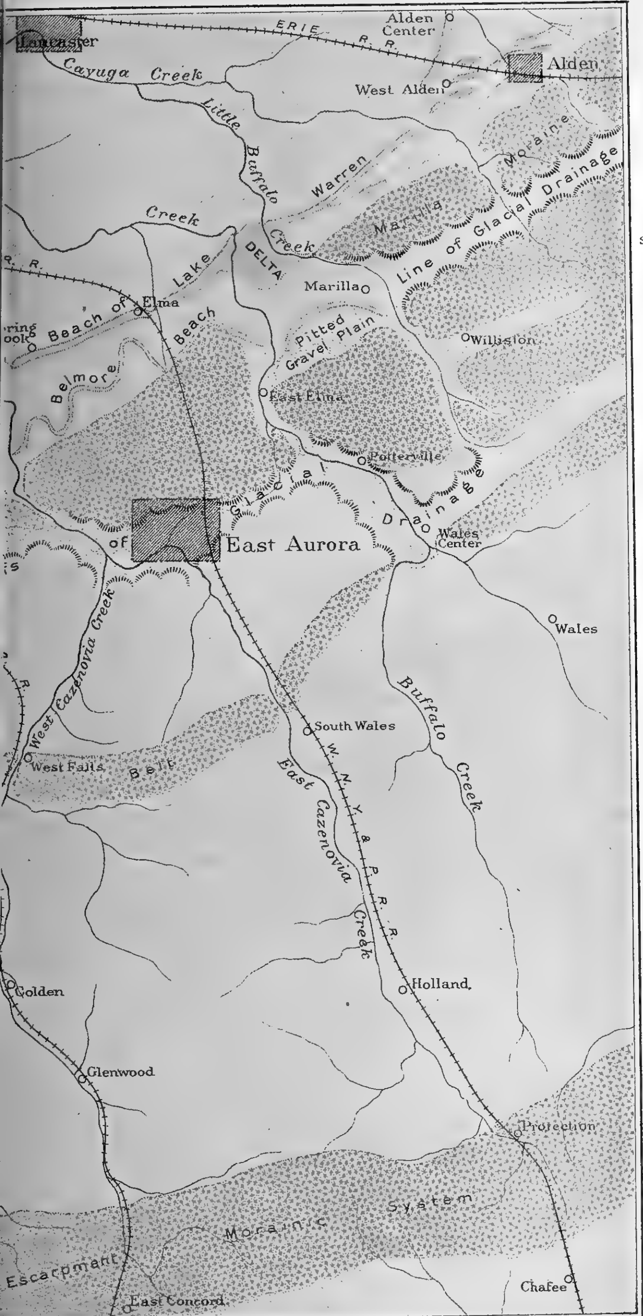


PLEISTOCENE FEATURES SOUTHEAS

BY FRANK LEVERE

Scale

1900



LEGEND

Morainic drift with many bowlders

Drift with nearly plane surface and few bowlders

Outwash gravel and lines of glacial drainage

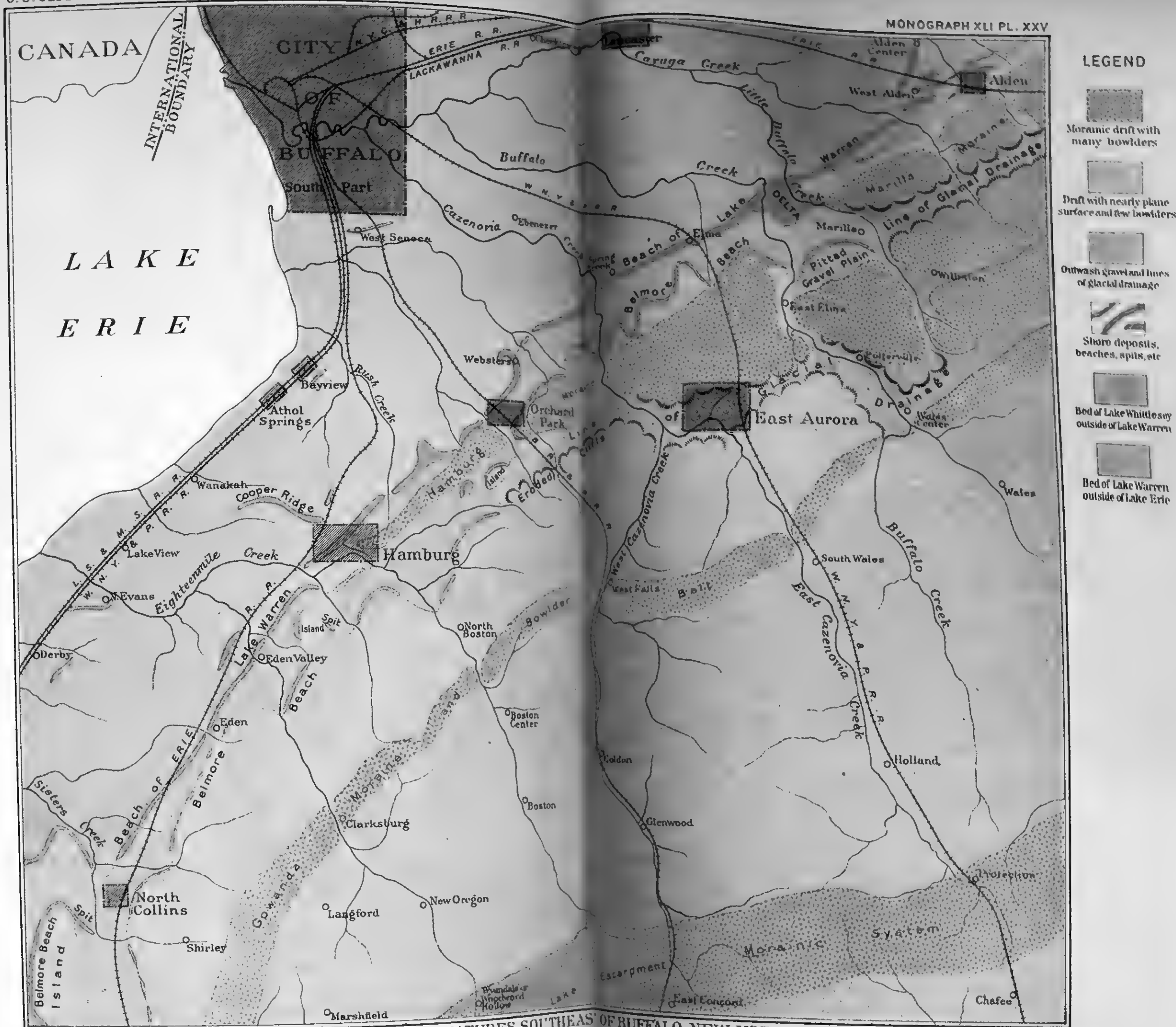
Shore deposits, beaches, spits, etc

Bed of Lake Whittlesey outside of Lake Warren

Bed of Lake Warren outside of Lake Erie

OF BUFFALO, NEW YORK

4 5 Miles
5 Kilometers



PLEISTOCENE FEATURES SOUTHEAST OF BUFFALO, NEW YORK

BY FRANK LEVERETT

Scale

1900

cut bank, but eastward from there to Elyria and thence to Cleveland it consists usually of a well-defined gravelly ridge similar in strength to the ridge which forms the west shore of the lake. It seldom rises more than 10 feet above the plain north of it, and is usually but 50 to 100 yards in width. In the western part of Cleveland it extends out as a spit, 15 or 20 feet high, from the prominent point in West Cleveland a mile or more toward the Cuyahoga River. In the eastern part of Cleveland it consists mainly of a cut bank.

From Cleveland northeastward as far as the vicinity of Dunkirk, N. Y., the beach is a very conspicuous feature, often presenting a cut bank 20 to 30 feet or more in height. As this bank was cut in a plain of gradual slope the shore must have worked back in some cases a mile or more to produce so high a bank. The exceptional strength of this portion of the shore seems attributable to its frontage toward the heavy seas raised by the winds from the west.

The strength of the beach begins to wane near the western end of the Gowanda moraine south of Dunkirk. The weakness on the south side of the Cattaraugus Valley is not surprising, since that portion of the shore would be directly exposed only to the waves produced by winds from the north, and such winds are less frequent and violent than winds from the west. But the portion of the shore north of Cattaraugus Creek had a frontage directly toward the west, and yet the strength of the beach is far below that displayed by similarly exposed parts of the shore west of Dunkirk. Continuing northeastward across the Hamburg moraine the shore becomes still weaker, and although fronting the northwest its strength is even inferior to that of the portions of the shore in Michigan and Ohio which front the east and northeast. The beach is commonly a ridge only 3 to 6 feet high and 50 yards or less in width. This diminution in strength, as already remarked, fits in naturally with the interpretation that the lake is of glacial age, and that the moraines between the lake escarpment system and the Marilla moraine are the correlatives of the beach.

VARIATIONS IN ALTITUDE.

The altitude of the beach on the south shore of Lake Whittlesey has very little variation from the Maumee River near Defiance eastward to the vicinity of Ashtabula, Ohio, a distance of 200 miles, the lowest measured

altitude being 731 feet and the highest 742 feet above tide. A part of this difference may be due to discrepancies between railway surveys and a part to the difference in the height to which the beach was built above mean lake level. These elements of error and of variation being eliminated, it is doubtful if enough difference will remain to require any crust warping.

Eastward from Ashtabula, the beach is found by levels on the Girard topographic sheet to reach 746 feet at the Ohio-Pennsylvania line, 748 feet near East Springfield, Pa., and 752 feet 4 miles farther east, while levels run by Taylor show it to be 765 feet at Swanville. This gives the beach a rise of 19 feet in a distance of about 19 miles. At Erie, 10 miles farther east, the city levels show the altitude to reach 772 feet, and at Northeast, 15 miles farther, levels run by Gilbert show the beach to be 788 feet above tide. Near the Pennsylvania–New York line, about 5 miles from Northeast, the profile of the Lake Shore and Michigan Southern Railway shows the altitude to be only 785 feet, but in the next 10 miles to Chautauqua Creek, south of Westfield, the beach, as shown by the Westfield topographic sheet, rises above the 800-foot contour. About 20 miles farther, near Fredonia, as shown by the Dunkirk topographic sheet, the beach rises above the 820-foot contour. Near Sheridan, 6 miles farther, Gilbert found the altitude by Locke level to be 834 feet. Six miles farther, near Hanover Center, the beach reaches the 840-foot contour. From Hanover Center to Cattaraugus Creek the course of the beach is south of east, or nearly at a right angle to the direction of uplift, and it holds a very uniform level at about 840 feet. It is very nearly 840 feet on the east side of Cattaraugus Creek, near the Indian Council House, as determined by spirit level by Fairchild from Lawton station. Four miles north, opposite North Collins, as determined by Locke level from North Collins station, it reaches 850 feet, being 20 feet above the railway station. Beyond this point measurements were made only with the aneroid, but these show a strong increase, the altitude southeast of Hamburg being 875 feet and near Elma station 890 feet. At the supposed terminus in Marilla the aneroid indicates an altitude of nearly 900 feet.

The rise of about 150 feet between the Ohio-Pennsylvania line and Marilla, N. Y., is made in a distance by direct line of not more than 125 miles, and contrasts strikingly with the variation of less than 15 feet in the 200 miles west from the Ohio-Pennsylvania line.

CAUSE FOR THE LOWERING OF THE LAKE.

It is probable that the lake level was lowered through the opening of lower passages than the Ubly outlet, either across or around the north end of the thumb of Michigan. Taylor has noted channels and scourways among the morainic hills north of the Ubly outlet that seem to have afforded outlets sufficiently low and capacious to have drawn down the lake level.[1] As that region is now (in 1901) under investigation, the precise relations will probably soon be determined.

[1] Bull. Geol. Soc. America, Vol. VIII, 1897, pp. 47–48.

CHAPTER XVI.

THE GLACIAL LAKE WARREN.

INTRODUCTORY.

The names Lake Warren, Warren Waters, and Warren Gulf have been applied by Spencer to the most extensive sheets of water in the Great Lakes region, and have been variously applied by other geologists. This has led to some confusion, and in order to make the application more specific Taylor has proposed to restrict the name Lake Warren to the body of water which existed when the fourth beach of Gilbert was forming. At that time the water in the Erie-Huron Basin seems to have had its greatest extent, and this meets as nearly as practicable the application made by Spencer. As this restriction of the name is a matter of some consequence, Taylor's reasons are here given:[1]

When Dr. Spencer had traced parts of the Forest, Arkona, and Ridgeway beaches in Ontario, he named the water which made them Lake Warren, in honor of Gen. G. K. Warren, whom he regards as "the father of lacustrine geology in America." This name was first published in Science for January 27, 1888, page 49; but in this and in all his subsequent publications relating to these beaches, Dr. Spencer had stated his belief that they are really of marine origin. Besides calling the waters that made these beaches Lake Warren, he has as frequently called them Warren Water and Warren Gulf. The current ideas of their size and origin have been diverse from the beginning, so much so as to make the application of the name rather uncertain. Dr. Spencer has always defined Lake Warren as covering the whole of the Great Lakes area, and Upham and Lawson have supposed it to cover all but Lake Ontario. The whole series of beaches has been regarded as the work of one lake at as many halts in the fall of its level. This is true in a wide sense, but there were so many elements of change as the waters fell that it seems appropriate and necessary to consider the several stages as separate lakes and give a special name to each. The waters changed their shape, size, and level as they fell, and, what seems still more important, they changed the place of their outlet several times.

The need for the restricted use of the name Lake Warren here proposed is a natural result of the progress of discovery. With the finding of outlets and terminal moraines intimately related to the beaches, the moraines marking the place of the ice barrier that held the waters up, it becomes a positive necessity to recognize the

[1] Bull. Geol. Soc. America, Vol. VIII, 1897, pp. 56–57.

MICHIGAN

1 MASON
2 LAKE
3 OSCEOLA
4 CLARE
5 GLADWIN
6 ARENAC
7 HURON
8 BAY
9 MIDLAND
10 ISABELLA
11 MECOSTA
12 NEWAYGO
13 OCEANA
14 MUSKEGON
15 MONTCALM
16 GRATIOT
17 SAGINAW
18 TUSCOLA
19 SANILAC
20 ST CLAIR
21 LAPEER
22 GENESEE
23 SHIAWASSEE
24 CLINTON
25 IONIA
26 KENT
27 OTTAWA
28 ALLEGAN
29 BARRY
30 EATON
31 INGHAM
32 LIVINGSTON
33 OAKLAND
34 MACOMB
35 WAYNE
36 WASHTENAW
37 JACKSON
38 CALHOUN
39 KALAMAZOO
40 VAN BUREN
41 BERRIEN
42 CASS
43 ST JOSEPH
44 BRANCH
45 HILLSDALE
46 LENAWEE
47 MONROE

INDIANA

1 LAPORTE
2 ST. JOSEPH
3 ELKHART
4 LAGRANGE
5 STEUBEN
6 DEKALB
7 NOBLE
8 KOSCIUSKO
9 MARSHALL
10 STARKE
11 PULASKI
12 FULTON
13 WHITLEY
14 ALLEN
15 ADAMS
16 WELLS
17 HUNTINGTON
18 WABASH
19 MIAMI
20 CASS
21 CARROLL
22 HOWARD
23 GRANT
24 BLACKFORD
25 JAY
26 RANDOLPH
27 DELAWARE
28 MADISON
29 TIPTON
30 CLINTON
31 BOONE
32 HAMILTON
33 HENRY
34 WAYNE
35 HANCOCK
36 MARION
37 HENDRICKS
38 MORGAN
39 JOHNSON
40 SHELBY
41 RUSH
42 FAYETTE
43 UNION
44 FRANKLIN
45 DECATUR
46 BARTHOLOMEW
47 BROWN
48 JACKSON
49 JENNINGS
50 RIPLEY
51 DEARBORN
52 SWITZERLAND
53 JEFFERSON
54 SCOTT
55 WASHINGTON
56 CLARK
57 FLOYD
58 HARRISON

OHIO

1 WILLIAMS
2 FULTON
3 LUCAS
4 OTTAWA
5 LAKE
6 ASHTABULA
7 TRUMBULL
8 GEAUGA
9 CUYAHOGA
10 LORAIN
11 ERIE
12 SANDUSKY
13 WOOD
14 HENRY
15 DEFIANCE
16 PAULDING
17 PUTNAM
18 HANCOCK
19 SENECA
20 HURON
21 MEDINA
22 SUMMIT
23 PORTAGE
24 MAHONING
25 COLUMBIANA
26 STARK
27 WAYNE
28 ASHLAND
29 RICHLAND
30 CRAWFORD
31 WYANDOT
32 ALLEN
33 VAN WERT
34 MERCER
35 AUGLAIZE
36 HARDIN
37 MARION
38 MORROW
39 KNOX
40 HOLMES
41 COSHOCTON
42 TUSCARAWAS
43 CARROLL
44 HARRISON
45 JEFFERSON
46 BELMONT
47 GUERNSEY
48 MUSKINGUM
49 LICKING
50 DELAWARE
51 UNION
52 LOGAN
53 SHELBY
54 DARKE
55 MIAMI
56 CHAMPAIGN
57 CLARK
58 MADISON
59 FRANKLIN
60 PICKAWAY
61 FAIRFIELD
62 PERRY
63 MORGAN
64 NOBLE
65 MONROE
66 WASHINGTON
67 ATHENS
68 HOCKING
69 VINTON
70 ROSS
71 FAYETTE
72 GREENE
73 MONTGOMERY
74 PREBLE
75 BUTLER
76 WARREN
77 CLINTON
78 HIGHLAND
79 PIKE
80 JACKSON
81 MEIGS
82 GALLIA
83 LAWRENCE
84 SCIOTO
85 ADAMS
86 BROWN
87 CLERMONT
88 HAMILTON

KENTUCKY

1 BOONE
2 KENTON
3 CAMPBELL
4 GREENUP
5 LEWIS
6 MASON
7 BRACKEN
8 PENDLETON
9 GRANT
10 GALLATIN
11 CARROLL
12 TRIMBLE
13 OLDHAM
14 HENRY
15 OWEN
16 HARRISON
17 ROBERTSON
18 FLEMING
19 CARTER
20 BOYD
21 LAWRENCE
22 ELLIOTT
23 ROWAN
24 BATH
25 NICHOLAS
26 BOURBON
27 SCOTT
28 FRANKLIN
29 SHELBY
30 JEFFERSON
31 BULLITT
32 SPENCER
33 ANDERSON
34 WOODFORD
35 FAYETTE
36 CLARK
37 MONTGOMERY

NEW YORK

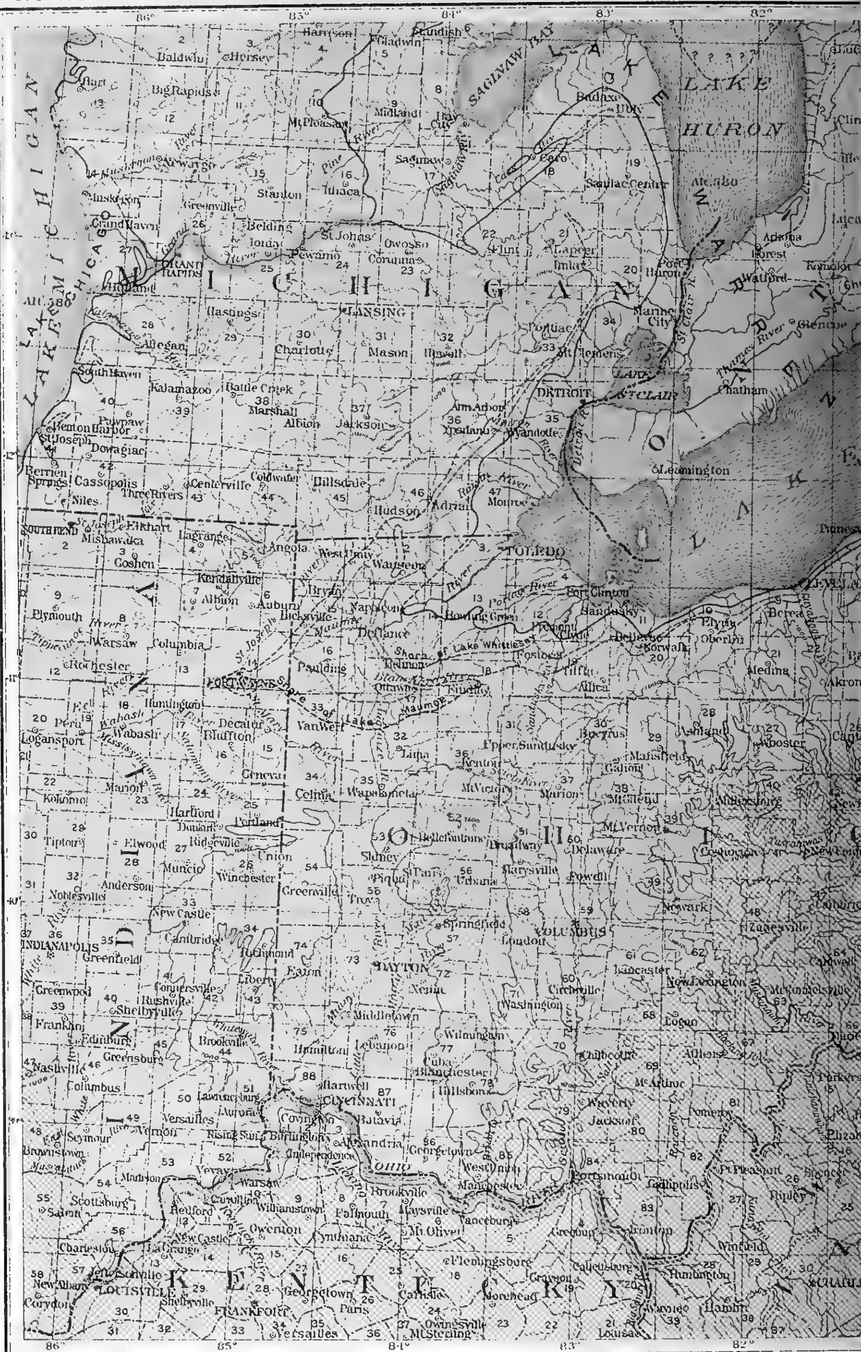
1 JEFFERSON
2 LEWIS
3 ONEIDA
4 OSWEGO
5 CAYUGA
6 WAYNE
7 MONROE
8 ORLEANS
9 NIAGARA
10 ERIE
11 GENESEE
12 WYOMING
13 LIVINGSTON
14 ONTARIO
15 YATES
16 SENECA
17 ONONDAGA
18 MADISON
19 CHENANGO
20 CORTLAND
21 TOMPKINS
22 SCHUYLER
23 BROOME
24 TIOGA
25 CHEMUNG
26 STEUBEN
27 ALLEGANY
28 CATTARAUGUS
29 CHAUTAUQUA

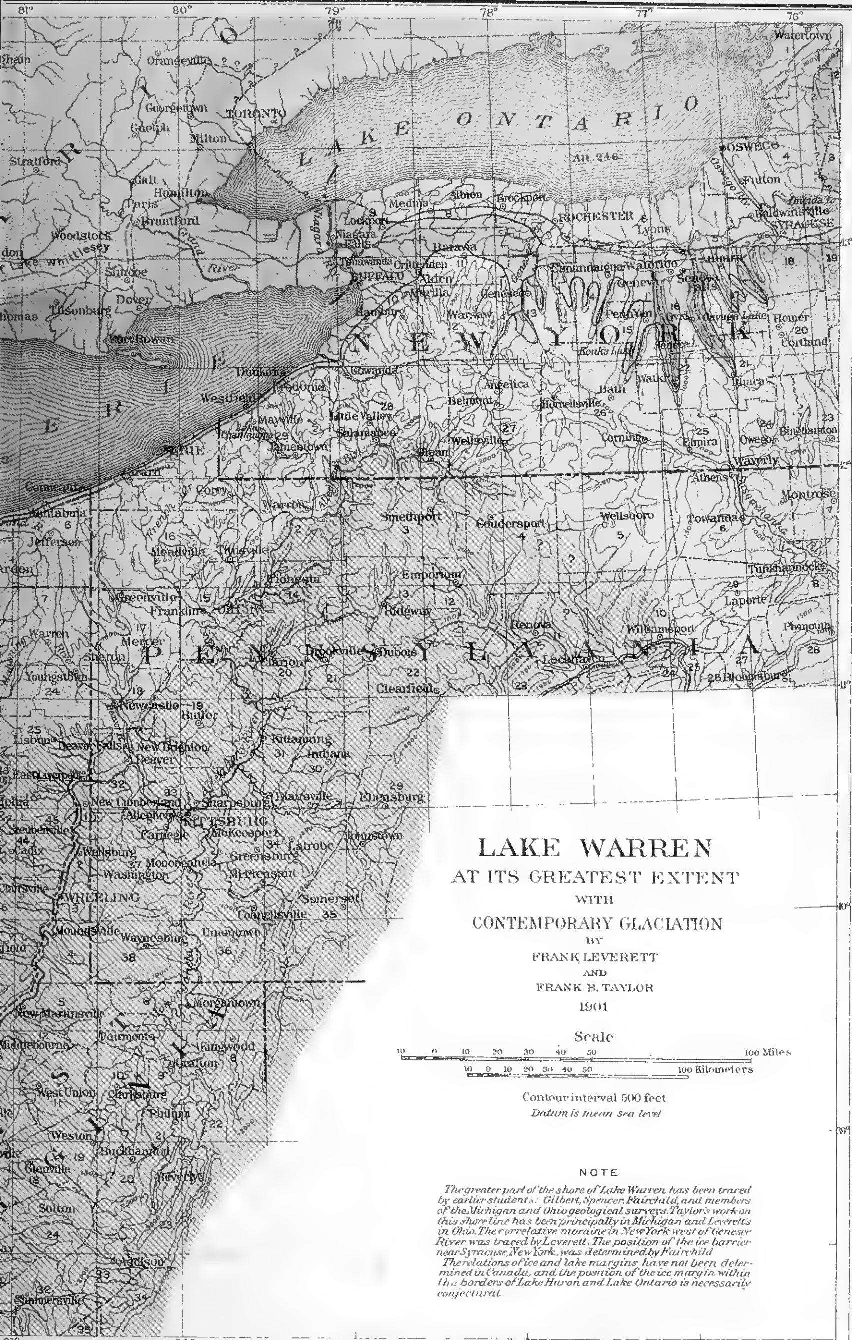
PENNSYLVANIA

1 ERIE
2 WARREN
3 MC KEAN
4 POTTER
5 TIOGA
6 BRADFORD
7 SUSQUEHANNA
8 WYOMING
9 SULLIVAN
10 LYCOMING
11 CLINTON
12 CAMERON
13 ELK
14 FOREST
15 VENANGO
16 CRAWFORD
17 MERCER
18 LAWRENCE
19 BUTLER
20 CLARION
21 JEFFERSON
22 CLEARFIELD
23 CENTER
24 UNION
25 NORTHUMBERLAND
26 MONTOUR
27 COLUMBIA
28 LUZERNE
29 CAMBRIA
30 INDIANA
31 ARMSTRONG
32 BEAVER
33 ALLEGHENY
34 WESTMORELAND
35 SOMERSET
36 FAYETTE
37 WASHINGTON
38 GREENE

WEST VIRGINIA

1 HANCOCK
2 BROOKE
3 OHIO
4 MARSHALL
5 WETZEL
6 MONONGALIA
7 MARION
8 PRESTON
9 TAYLOR
10 HARRISON
11 DODDRIDGE
12 TYLER
13 RITCHIE
14 PLEASANTS
15 WOOD
16 WIRT
17 CALHOUN
18 GILMER
19 LEWIS
20 UPSHUR
21 BARBOUR
22 TUCKER
23 RANDOLPH
24 BRAXTON
25 ROANE
26 JACKSON
27 MASON
28 CABELL
29 PUTNAM
30 KANAWHA
31 CLAY
32 NICHOLAS
33 WEBSTER
34 POCAHONTAS
35 GREENBRIER
36 FAYETTE
37 BOONE
38 LINCOLN
39 WAYNE





LEGEND

Glacial lakes and drainage

Ice covered

Previously glaciated, border incomplete east of longitude 76°

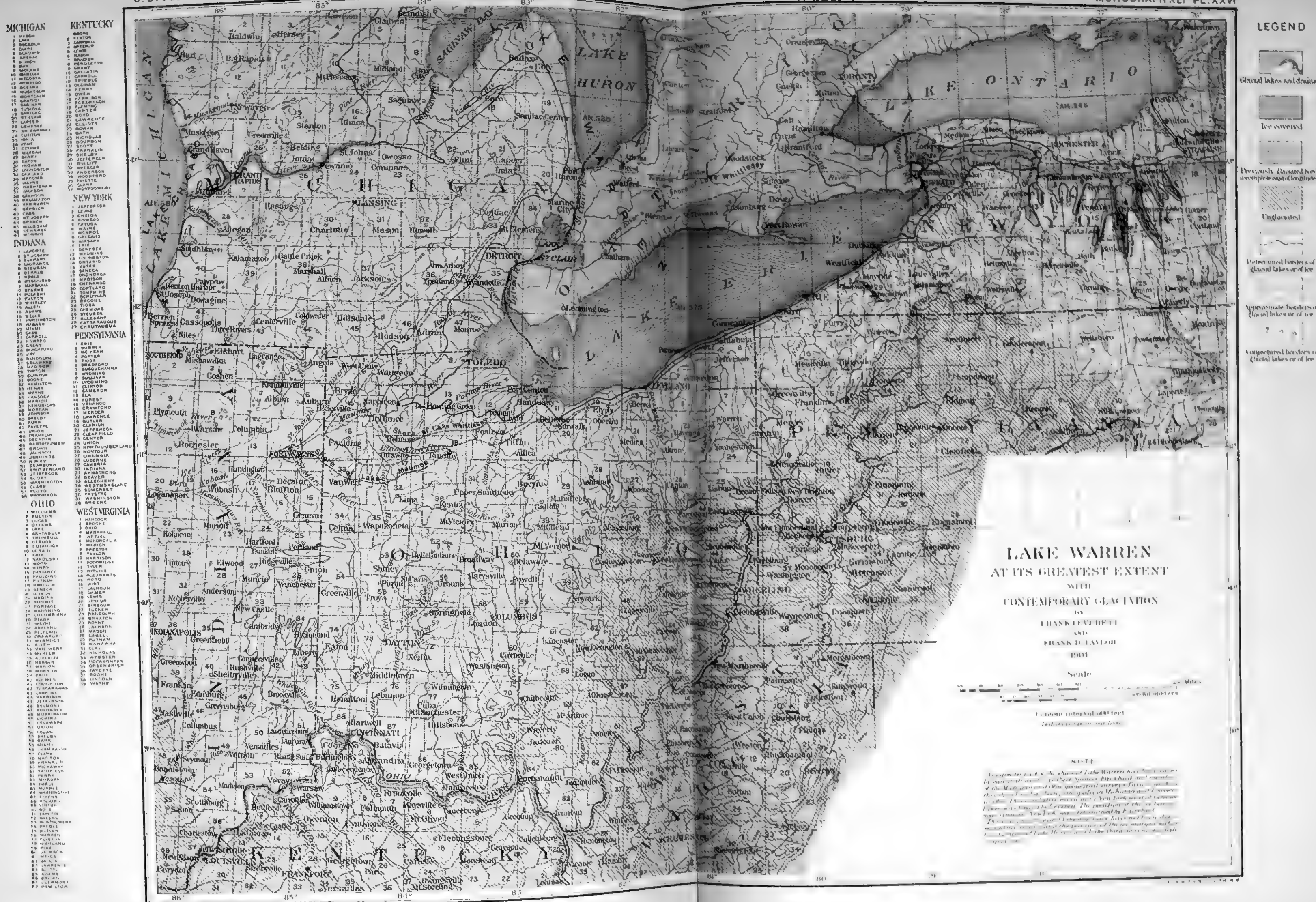
Unglaciated

Determined borders of glacial lakes or of ice

Approximate borders of glacial lakes or of ice

Conjectured borders of glacial lakes or of ice

JULIUS BIEN & CO. LITH N.Y.


LAKE WARREN
AT ITS GREATEST EXTENT
WITH
CONTEMPORARY GLACIATION
BY
FRANK LEVERETT
AND
FRANK B. TAYLOR
1904
Scale
LEGEND
Glacial lakes and drainage
Ice covered
Unglaciated
Determined borders of glacial lakes or of ice
Approximate borders of glacial lakes or of ice
Conjectured borders of glacial lakes or of ice
MICHIGAN
KENTUCKY
NEW YORK
INDIANA
PENNSYLVANIA
OHIO
WEST VIRGINIA
LAKE HURON
LAKE ONTARIO
LAKE MICHIGAN
LAKE ERIE
LAKE ST. CLAIR

new facts, and this can be done best, as it seems to the writer, by subdivision and restriction in nomenclature, as is sometimes done in the biological sciences. The whole series of lakes here described might be called the Warren lakes. This would be one way of preserving Spencer's nomenclature, but in the writer's opinion this use of the name would be unfortunate. A collective name ought to have some geographic significance. The name Erie-Huron, which is used here, serves this purpose admirably, and the name Lake Warren may then be applied in a more restricted way to that one of the several separate lakes of the series which most closely corresponds to Spencer's original idea. The Forest beach marks the widest extent of the Erie-Huron glacial waters, and was the last and most extensive lake of the series. It seems more appropriate, therefore, to call this stage Lake Warren than to apply this name to any of the higher, less extensive stages.

The Lake Warren beaches as here discussed and as mapped in Pl. XXVI, include the whole of a complex series which occupy levels about 50 to 75 feet below the Belmore beach. The members of this series are more distinct from Cleveland eastward than around the western end of the Erie Basin. Wind-drifted sand greatly confuses the shore features in the latter region.

Perhaps the upper ridge, to which Spencer applied the name Arkona beach, is sufficiently distinct from those below it to justify separating it from the Lake Warren series. Taylor has considered it the product of a distinct but transient lake, and does not include it in this series. In southern Michigan it lies along the outer border of the same belt of sand which in Ohio constitutes Gilbert's fourth beach, but being composed usually of gravelly material, it may be distinguished from the belt of clear sand which it borders. Its gravelly ingredient seems to disappear in northwestern Ohio, so that it can not well be separated from the remainder of the sand belt. The Woodland avenue beach at Cleveland seems likely to be a continuation of the Arkona beach, and the upper member of the series from Cleveland eastward should probably also be thus considered. The upper limits of sand ridges in the district south of the western end of Lake Erie is also about at the level of the Arkona beach.

The writer has examined this series of beaches at but few points in Michigan, and as they are soon to receive further study in that State, the description will extend no farther north than the Ohio-Michigan line. The only detailed work which the writer has attempted on these beaches is in the district between the Maumee and Vermilion rivers in northwestern Ohio and in Erie and Genesee counties, N. Y. The portion north of the Maumee had been mapped by Gilbert, and the portion between the Vermilion

River and Cleveland by A. A. Wright, while the portion between Cleveland, Ohio, and Cattaraugus Creek in New York has long been known to the geologists who have made investigations in that region. Fairchild has continued the examination of the Warren shore from Erie County, N. Y., eastward beyond the Genesee River, as indicated below. The outlet of Lake Warren appears to have been westward from Saginaw Bay through Spencer's "Pewamo Strait"[1] to Lake Chicago, in the southern end of the Lake Michigan Basin, and thence through the Chicago outlet to the Illinois and Mississippi rivers. But as this, as well as the part of the beach in Michigan, is soon to be made the subject of further study, a description will not be attempted in this place.

DESCRIPTION OF THE BEACHES.

The portion in Ohio north of Maumee River is reported by Gilbert to be a broad belt of sand, chiefly in the form of dunes but nearly level on the inner margin. The altitude of the sand extends from about 90 feet above Lake Erie down to 60 feet, or even lower. The western border leads from the Ohio-Michigan line near Sylvania southwestward to Napoleon. Gilbert remarks that the border is not so definite as it would need to be to admit of easy mapping, but stands near the line just indicated. The inner border of the sand belt touches the Maumee for a short distance just above Toledo, but for several miles farther it lies 2 or 3 miles back from the river, after which it again extends to the river.

Sherzer's studies, which have been extended southward from Michigan a short distance beyond the State line, have brought to light a range of sand ridges standing between 650 and 660 feet, which he considers the Forest beach. This range has not been examined by the writer, but upon inspection of the Toledo topographic sheet it is found that the rise is quite abrupt between the 640 and 660 foot contours, as if the lake had cut back its shore there.

In the district between the Maumee and Sandusky rivers there are several conspicuous ridges of sand and belts of dunes whose altitude is more than 100 feet above Lake Erie. The plains on the border of these ridges have generally an altitude about 100 to 115 feet above the lake, or 670 to 685 feet above tide, and the main lake level appears to have been

[1] Am. Jour. Sci., 3d series, Vol. XLI, 1891, p. 207.

between 680 and 690 feet. This altitude harmonizes more nearly with the Arkona beach than with the Forest. There seems to be no definite shore in this district below the level of these sand ridges to correlate with the Forest beach. The general altitude is 15 to 20 feet higher than Gilbert's estimate of the sand in the district north of the Maumee. It is possible, however, that the sand north of the river reaches an equally high altitude, Gilbert's estimates having been made when there were fewer data than now concerning altitudes.

There is a strip of sand south of the Maumee River setting in a mile or so above Napoleon and leading nearly due east for 9 or 10 miles. It consists of a series of overlapping ridges that trend west-southwest to east-northeast. The well-defined ridges are usually continuous for 1 to 2 miles, but several are a half mile or less in length. The ridges are 10 to 20 feet in height and 50 to 100 yards or more in width. The base seems to be nearly uniform at an altitude about 680 feet above tide. The mode of overlapping is such as to indicate that the ridges were built up successively in a series from east to west by winds blowing from the west.

From the eastern end of this system of ridges near McClure there is an interval of about 8 miles to Weston, in which the sand shows only occasional ridging but forms a thin coating on the plain. The trend of this part of the shore being southeastward it was unfavorably situated for the action of the west or strong winds. At Weston a prominent sand ridge sets in which leads in an east-northeast course to Bowling Green, a distance of 8 miles, and is continued in faint form 8 miles farther in the same direction along the north side of Portage River. The altitude of the plain north of this ridge is about 675 feet above tide, and there appears to have been a shore near the line of this sand ridge; but the ridge was evidently wind drifted. Its highest points rise above the 700-foot contour, and one dune in Bowling Green reaches 720 feet.

There are occasional sand ridges north of this main ridge. A conspicuous instance is found in a belt of ridged sand which sets in near Craws station, 4 miles north of Bowling Green, and leads west-southwest, with occasional gaps, 3 or 4 miles. The base of this sandy belt stands near the 670-foot contour, as shown by the electric railroad profile, and the ridges rise 5 to 20 feet above that level. A sand bar seems to have formed here at about lake level that was subsequently ridged by wind. East from

Craws a rock ridge sets in which stands 8 to 10 feet above the plain and leads eastward past Sugar Ridge village. This also received a sand coating.

For several miles south from Bowling Green small sand ridges appear which seem to have been formed by the wind from sand deposited in a shallow bay that extended up Portage Valley a little farther west than the meridian of Bowling Green. This bay must have been very shallow, for the railway altitudes at Mermill and Mungen indicate that its bottom was about 685 feet. From near Rudolph, about 8 miles south of Bowling Green, a belt of sand leads eastward through Jerry, and thence northeastward through Freeport and Bradner into the edge of Sandusky County. It is about as strong as the one which passes through Bowling Green, the dunes being from 10 to 25 feet in height and the belt of sand about one-fourth mile in average width. The lake seems to have extended southward on the line of Wood and Sandusky counties nearly to Rising Sun, for another sandy belt sets in a mile east of that village which leads northeastward about to Helena. This sand belt is in places nearly a half mile in width and has been drifted into dunes 10 to 20 feet in height. It is the easternmost prominent sand belt found in the district between the Maumee and Sandusky rivers. A few low sand ridges appear between Helena and Haven station (4 miles west of Fremont), but they are seldom more than 10 feet in height and but a fraction of a mile in length.

A well-defined gravelly beach leads past Haven station in a course from north-northwest to south-southeast. It can be traced from the southeast corner of section 2, Jackson Township, to the south side of section 13, a distance of over 2 miles. Its height is 4 to 8 feet and breadth 50 to 75 yards. For about a mile south from the south end of this beach no ridge is found, but low sand ridges there set in which continue the shore in a southeastward course to Sandusky River near the mouth of Wolf Creek, about 6 miles above Fremont.

On the east side of Sandusky River there is a sandy plain extending from Fremont southward into the edge of Seneca County. A few low ridges, 5 to 10 feet high, are found about 6 miles south of Fremont in sections 33, 34, and 35, Ballville Township, Sandusky County, which probably constitute the continuation of the beach. The beach becomes more definite in section 19, Green Creek Township, and from that point runs in an east-northeast course to Clyde. The altitude at Clyde is about 680 feet and

barometric determinations give the ridges in Ballville Township a similar altitude. There appears to be no well-defined lower shore north or west of Clyde. Sand ridges appear east and south of the village up to an altitude about 710 feet above tide. These, however, were probably drifted by wind above the level of the old lake.

From Clyde a very definite shore leads northeastward to Castalia. It presents usually a cut bank 10 feet or more in height, on whose face and crest deposits of sandy gravel occur. There are also sandy ridges for some distance south of this old shore. Before reaching Castalia the beach comes to a limestone cliff and follows its western base past that village. At the north end of the cliff, about a mile northeast of Castalia, the beach turns eastward and recurves as a spit along the east side of the cliff.

From this cliff southeastward for several miles the beach is ill defined, though sandy ridges near Bloomingville and Prouts station seem to represent it (see Pl. XXII). About a mile east of Prouts a definite ridge of sandy gravel sets in which leads southeast another mile. Back of it a slightly higher ridge appears and leads southward to Huron River, passing just east of the village of Enterprise. It crosses Huron River 3 miles west of Milan, near the line of Erie and Huron counties. This ridge is composed of sandy gravel, is 3 to 6 feet in height and 50 to 75 yards in width. It is remarkably regular for 3 miles north from Huron River and also for a similar distance on the east side of that stream in northern Huron County.

On Marblehead Peninsula, north of Sandusky Bay, there is a small tract which stands sufficiently high to catch what appears to be the Forest beach. Its altitude is very nearly 100 feet above Lake Erie, or 670 to 675 feet above tide. It is developed for a distance of fully 2 miles, setting in about a mile east of Lakeside and following the north border of the peninsula to that village, after which it bears southwestward into the interior. It is a low ridge, 3 to 5 feet high, composed in large part of blocks of limestone, but occasionally containing gravel. The rocky character of this beach is strikingly similar to that of the shore of Lake Erie below it, where the waves are now piling up blocks of limestone derived from the cliffs of the peninsula.

The beach which crosses Huron River 3 miles above Milan presents a well-defined gravelly ridge as far east as that village, but is rather indefinite from there northeastward to Vermilion River because of wind action,

there being a belt of dunes at about its level. From Vermilion River to Cleveland the main shore is a remarkably distinct and nearly continuous ridge of sandy gravel which in a few places becomes drifted into dunes. It crosses Black River about 4 miles north of Elyria and leads through the villages of Avon and North Dover, as indicated in the map prepared by A. A. Wright for the Geology of Ohio.[1] It leads into Cleveland from the west along or near Detroit street, and after crossing the Cuyahoga River lies near Euclid avenue to the east edge of the city. From the point where it enters the city eastward nearly to the Cuyahoga, there is a bank 10 to 15 feet in height cut in the till which is capped by small deposits of gravel; but from near the river eastward it is built on the sand and gravel delta of the Cuyahoga and presents a smooth ridge, standing slightly above the plain south of it and 5 to 10 feet or more above the plain on the north.

There is in Cleveland a higher and weaker beach known as the Woodland avenue beach, which stands about 20 feet above the main beach. Its altitude, as determined by Upham,[2] is 115 to 120 feet above Lake Erie or about 690 feet above tide, while the main beach is 95 to 100 feet above the lake or about 670 feet above tide. The upper one consists usually of a well-defined gravelly ridge, 3 to 8 feet in height and 50 to 75 yards in width, but in places is sandy and forms a broad swell, 100 to 200 yards in width. This upper shore seems to have about the altitude of the Arkona beach, while the lower apparently corresponds to the Forest beach. It is probably the Forest beach that Wright mapped as the "North Ridge," from the Vermilion River eastward to Cleveland, while the Arkona has not been mapped in that region.

The portion of the shore from Cleveland eastward to the Cattaraugus Valley in western New York has received only incidental notice, but the beaches are known to be well defined throughout the entire interval of more than 150 miles and to stand only 2 to 4 miles back from Lake Erie. They are more sandy than the Belmore beach and dunes are very common. Usually there is a single strong ridge, which is known as the "north ridge," the Belmore ridge being called the "south ridge." But at many points two, and in places, three, ridges are found whose levels differ but a few feet. The main ridge is commonly the lowest in the series, and stands 65 or 70

[1] Geology of Ohio, Vol. II, 1874, p. 58.

[2] Bull. Geol. Soc. America, Vol. VII, 1896, p. 343.

feet below the Belmore. The remaining bars or beaches are variable in altitude and in number, as well as in strength, and the causes or conditions which produced them are not at present clearly understood. The lowest or main beach marks a well-defined, long-continued lake level.

The shore of Lake Warren, like that of Lake Whittlesey, shows marked differential uplift in passing eastward from the Ohio-Pennsylvania line. At the State line the upper ridge stands very near the 700-foot contour, while a lower ridge is shown by the Girard topographic sheet to be 678 feet above tide. The latter is the main beach between Cleveland and the State line and seems to be the Forest. Its altitude is less than 10 feet higher than at Cleveland though the distance from Cleveland to the State line is nearly 70 miles.

From the Ohio–Pennsylvania line eastward to Westfield, N. Y., a distance of 50 to 55 miles, the first or uppermost ridge rises 42 feet, or to 742 feet as determined by Locke level from the railway station, while a second ridge stands 717 feet and a third ridge 705 to 707 feet above tide. At this place the second ridge is much weaker than the first and third ridges, yet its altitude, if compared with the first ridge, supports the view that it is the continuation of the Forest beach or second ridge found at the State line, the interval in each place being not far from 25 feet. The third ridge, though well defined at Westfield, with a bank 8 to 10 feet in height, seems not to have been developed extensively along the south shore of the lake.

The beaches continue to rise as far as the vicinity of Silver Creek, 25 miles beyond Westfield, but for a few miles from that place the shore bears south of east to Cattaraugus Creek, near Versailles, and the beaches show but little change in altitude. For much of the way between Westfield and Cattaraugus Creek there are only two ridges. The upper one reaches the 780-foot contour near Sheridan, and the lower one the 760-foot contour about 3 miles northeast of Sheridan, as shown by the topographic sheets.

The shore bears away from Lake Erie near Silver Creek, running up the south side of Cattaraugus Creek to Versailles, nearly 10 miles from the lake. It comes back only a short distance on the north side of Cattaraugus Creek. The best defined beach formed for a few miles north of the creek seems to be a continuation of the lower of the two ridges found west of the creek. It leads northeastward past Brant Center, and near Pontiac to

Eden, and thence to Hamburg. There is a complicated series of ridges from near Eden to Hamburg which apparently occupy the interval from the lower up to the higher ridge. At Hamburg there are two beaches which differ nearly 20 feet in altitude. The lower and weaker one, known as Cooper ridge, leads westward from Hamburg about 2 miles, directly away from the upper beach, following the crest of a ridge on the north side of Eighteenmile Creek. The upper or main ridge leads northeastward past Abbotts Corners, Websters Corners, Spring Brook, and Elma Center to West Alden, crossing Cazenovia Creek at Spring Brook, Buffalo Creek at its bend 3 miles northeast of Elma Center, and Cayuga Creek about a mile southwest of West Alden. On each of these streams, as well as on smaller streams, there are prominent deltas at the points where the beach crosses, and the beach itself is exceptionally strong throughout this part of its course. The lower ridge was traced only about 2 miles northeast from Hamburg and is reported to be ill-defined between there and West Alden. About 3 miles southwest of West Alden weak, sandy ridges were found back of the main ridge at a slightly higher altitude, but they seem to be of very limited extent and their significance is not clear. The main beach from Hamburg to Alden, like the Arkona beach of the western end of the Erie basin, stands only about 50 feet below the Belmore beach, but it is a stronger shore line.

At West Alden there is a separation into two distinct beaches, one of which leads eastward through Alden along the inner face of the Marilla moraine into Genesee County, where it dies out in a narrow plain standing between the Marilla and Alden moraines. The other beach bears northward through Alden Center, and thence northeastward past Crittenden, and comes to Tonawanda Creek at Indian Falls. The outer shore or beach seems to be a few feet higher than the inner, at least railway levels at Alden and Crittenden bear out this interpretation, the altitude at Alden being about 12 feet higher than at Crittenden, but at the point of separation near West Alden there is scarcely 5 feet difference.

The outer beach is remarkably strong clear to its terminus. It consists near Alden of a series of overlapping ridges trending northeast to southwest, which were apparently built up in succession from east to west. They are rather sandy but contain also considerable gravel, so that they can not be the product of wind alone.

The inner ridge is strong and nearly continuous from West Alden to a point about a mile east of the Erie and Genesee County line. It there dies out as a ridge, but appears as a cut bank on the western ends of the Pembroke ranges of gravel hills. A bay seems to have extended back along the north side of the north range of hills nearly to East Pembroke.

The altitude of the beaches shows a marked increase in this interval between Cattaraugus and Tonawanda Creeks. From an altitude of 780 feet at Cattaraugus Valley the upper beach rises to 810 feet at Hamburg, 840 feet at Elma Center, and fully 860 feet at Alden. The lower beach rises from 760 feet to 790 feet between Cattaraugus Creek and Hamburg. The inner ridge, leading north from West Alden, is only 850 feet at Crittenden, but rises to the 880-foot contour about a mile northeast of Indian Falls, as shown by the Medina topographic sheet. This beach was traced by the writer only to the brow of the Corniferous escarpment a short distance northeast of Indian Falls, but it has since been traced eastward by Fairchild beyond the Genesee River. This tracing by Fairchild has extended Lake Warren beyond the limits assigned by the writer in a paper published in 1895,[1] and is marked by his thoroughness and painstaking attention to details. The following description of the portion between Tonawanda Creek and the Genesee River is taken from Fairchild's recent paper:[2]

At Indian Falls the channel of Tonawanda Creek interrupts the beach for three-fourths of a mile, but it reappears in excellent form on the summit of the hill at the north edge of the village. A strong ridge of somewhat angular gravel lies upon the east side of the road and supports the house of Mr. C. T. Pratt. The southern end of this bar turns west, crosses the road, and then turning north runs along the west side of the road to a three corners. Here the bar swings eastward, crosses the road by the house of Mr. Bascom, then curving northward passes behind the house of Mr. Peter Lester. In a short distance the bar turns east, at which point another branch runs west, the latter crossing the road and terminating upon the crest of the Corniferous escarpment. The eastward branch soon breaks into a series of overlapping bars and spits of good development. Turning northward, in about one-half mile the beach crosses an east-and-west road, by which is an old gravel pit in the ridge and soon drops over the edge of the Corniferous limestone a few rods east of a north-and-south road. For a short distance the shore line is a cliff in the limestone, but quickly surmounts the escarpment as a well-developed ridge of almost clear chert.

[1] Correlations of New York moraines with raised beaches of Lake Erie: Am. Jour. Sci., 3d Series, Vol. L, 1895, pp. 1–20.

[2] Bull. Geol. Soc. America, Vol. VIII, 1897, pp. 274–277.

It is an interesting fact that the altitude of the Corniferous escarpment and the surface of the Warren waters were nearly coincident. From Indian Falls around to northeast of Batavia, a distance on the shore line of perhaps 20 miles, the beach is usually on the crest of the rock ledge as a ridge of nearly clear chert. At a few points the rock was higher than the water, and wave-cut cliffs are conspicuous. The best cliffs are south of Smithville, east of Daws Corners, and northeast of Batavia.

From the point last mentioned in the detailed description the beach follows the irregular crest of the rock escarpment for 2½ miles, crossing several highways, as shown in the map, and terminates behind a rock hill near a stone schoolhouse at three corners. A strong wave-cut cliff is seen upon the west end and north side of the hill which is an outlier of the Helderberg-Corniferous strata. About a mile west of the north-and-south, Smithville-Pembroke, road the shore line again becomes a ridge upon the drift-covered escarpment. The beach then runs south 1 mile and after some interruption in a kame area crosses at four corners to the south side of the east-and-west town-line road and breaks into several bars. Another very heavy ridge is found one-fourth of a mile north on land of Mr. Weber Stevens, in an old orchard on the east side of an old road. This ridge of gravel runs east and southeast 1 mile. At the next north-and-south road, leading south from Oakfield station on the West Shore Railroad, the shore line is a cliff in till, but soon resumes its normal character as a strong ridge of chert gravel along the south side of the east-and-west town-line road. For 3 miles the beach, as embankment or cliff, runs parallel with the road, close upon the south side, against the north side of the moraine or drift-covered terrane. It is generally 25 or 30 feet above the highway, which lies upon the lake floor, the latter stretching north as a smooth plain.

About a mile west of Daws Corners the strong bar curves southeast, then after a gap by stream erosion it swings by curves eastward to the Elba-Batavia road, which it crosses about one-half mile south of Daws Corners, close to the house of Mr. Sylvester Strong. The bar, which here is destitute of chert, ends about one-half mile east of the road in a heavy spit on the edge of a broad stretch of low ground. A wave-swept plain of sand borders the depression on the north with low spits running into the depression.

One-third of a mile south the shore line is conspicuous as a bold cliff in the east-and-west escarpment. Running eastward one-half mile, it becomes a bar and then makes a curve to northward lying on the summit of the high, steep escarpment of the Helderberg, about one-third of a mile south of the town-line road. At the extreme northern point the shore line is just beneath the very top of the escarpment, which is Corniferous. From this point the beach runs southeast 1 mile to the northeast-southwest road, at which point the ridge has been excavated for gravel. Here it is on the top of the escarpment as a good ridge, and so continues eastward for one-half mile, when it falls below the crest of the ledge and curves around to southward as a rock cliff for nearly 2 miles. The shore line crosses to the east side of the north-and-south town-line road, then after running along the road for about one-fourth of a mile it lies in the roadway for about the same distance, then recrosses to the west side, and in half a mile becomes a well-developed gravel ridge. In the ground of Mr. Charles Thornwell it bears a gravel pit, visible from the highway. Near the gravel pit the bar has been cut by drainage, and south of the gully a fine

ridge is found, with north-and-south direction, on the land of Mr. J. Miner. This is about 2½ miles northeast of the center of Batavia village.

East of Batavia village the moraine, with strong relief, lies partially below the Lake Warren level. The lake waters were here entangled among the hills, and the beach is broken for 2 miles, but two well-defined wave-cut cliffs are conspicuous. These are clearly seen from the main line of the New York Central Railroad, which, eastward from Batavia, traverses the moraine and descends rapidly upon the silt plain formed as the floor of the Warren waters. The more westerly cliff is upon the north and east side of a till ridge about 1 mile southeast of the bar last mentioned and about one-fourth of a mile east of the railroad. Well-defined but broken shore phenomena connect this cliff with another cliff in drift 1 mile farther eastward. The beach then runs northeast another mile, as a good ridge, to a strong cliff in Corniferous limestone, which shows excellently the effects of heavy wave action upon a headland. From this cliff a nearly continuous bar or ridge is found for the 6 miles to Leroy. * * *

The beach passes through the southern and higher part of the village of Morganville, and shows in good form both east and west of the village.

The altitude of the beach is here definitely known. One and one-half miles northeast of Morganville and about half a mile west of schoolhouse No. 3 is a station of the United States Lake Survey, located exactly upon the beach ridge, with a corrected altitude for surface of the ground of 880 feet. Upon the west side of the north-and-south road, by school No. 3, which is situated upon the beach, the crest of the beach is 4.56 feet under the top of rail of the Lehigh Valley Railroad at the road crossing one-fourth of a mile south. The altitude of rail is 884.60, making the crest of beach 880 feet. One-half mile farther east the railroad crosses the beach by a cutting, and the altitude is 879 feet.

Approaching Leroy, the beach becomes obscure upon a kame-like surface among low drumloids about one-fourth mile northwest of the railroad station. The level of the water surface passes through the lower or northern part of the village. The next appearance of the beach is a good gravel ridge about one mile east of the village, between the Leroy-Caledonia highway and the three railroads, on the land of Mr. A. H. Olmstead. The ridge curves around northeast of the farmhouse and barns, and once formed a hooked spit near the highway, which has been cut away for gravel.

Across a brook and upon the south side of the highway the beach reappears in excellent form as a heavy gravel ridge beneath the residence of Mr. Abram Van Valkenburg. For about a mile the ridge follows along the south side of the highway, slightly diverging and giving location for the residences upon that side of the road.

Eastward from here the ground is lower, with long, drumlin ridges. The shore line is exceedingly crooked and the beach phenomena obscure in the embayments, but usually pronounced at the north ends of the ridges. * * *

Within 3 miles of Caledonia the shore line is thrown rapidly southward upon the west side of the Genesee Valley embayment. The Warren waters occupied the valley of the present Genesee River as far south as Mount Morris. The accumulation of sand and silt either side of the gorge ("High Banks") west of the village

doubtless represents the delta deposits of the stream during the Warren episode, before the gorge was excavated. The waters occupied the preglacial valley of the river, now possessed by the Kishawa Creek as far as the village of Nunda, and numerous terraces and plateaus in that valley are thought to represent the work of those static waters.

Fairchild also describes in the same paper a well-defined beach on the east side of the Genesee Valley leading from near Geneseo northeastward to Lima. Since publishing that paper he has noted evidences of the presence of a body of water having the level of Lake Warren in the valleys of several of the Finger lakes of western New York.

In interpreting the lake history of that region he has called attention to a succession of lakes in these valleys.[1] The earliest lakes were formed as the ice sheet first began to recede from the southern end of the valleys. They seem to have been very small and of short duration. As the ice sheet withdrew passages were opened between the different valleys and a common level for several lakes was established with an outlet across the lowest pass to the south at Horseheads, N. Y. To the lake thus formed Fairchild had earlier applied the name Lake Newberry,[2] though at that time he supposed it to be a successor of Lake Warren. As the glacial retreat continued passages were opened between Lake Newberry and Lake Warren, and the former took the level of the latter. The Lake Warren waters appear to have advanced eastward with the retreat of the ice to the vicinity of Marcellus, N. Y., before a passage eastward to the Mohawk Valley became available. With the opening of this passage the lake level was lowered and Lake Warren closed its history.

The channel near Marcellus, which afforded a new outlet for the lake waters, was first brought to notice by Gilbert in connection with other channels in western New York,[3] but it remained for Fairchild to discuss the relations to Lake Warren. In the more recent of the two papers above cited Fairchild makes the following statements:

> Two miles south of Marcellus village a huge delta lies on the west side of the valley [Otisco], at the mouth of a great channel cut in the Hamilton shales. The topographic sheet gives the height of the delta terraces as 860 down to 800 feet. The delta is the débris derived from the excavation of the gorge and dropped by the

[1] Bull. Geol. Soc. America, Vol. X, 1899, pp. 27–68.

[2] Ibid., Vol. VI, 1895, pp. 462–466.

[3] Old tracks of Erian drainage in western New York: Bull. Geol. Soc. America, Vol. VIII, 1897, pp. 285–286.

powerful river in the slowly falling waters of the Otisco Valley. The gorge heads 4 miles northwest of Marcellus, and a mile west of Sheppards Settlement, on limestone, with an elevation at the intake, as given by Dr. Gilbert, of 812 feet. Here, at the head of the eroded "gulf" (the only local name), the drift and shale are removed down to the hard limestone rock over considerable area. It is evident that an enormous volume of water escaped at this point. This was the water of Lake Warren, which found here an outlet lower than its old one westward across Michigan to the Mississippi. Its western flow, that had been sustained perhaps some thousands of years, was, by the removal of the ice dam in this region, slowly reversed and shifted to the east toward the Mohawk-Hudson. This was the end of Lake Warren proper. For the similar body of water, but with falling surface and diminishing area, which found lower and lower outlets eastward along the ice front, we can have no specific name, but, using a generic term, may speak of it as the hyper-Iroquois waters.

The Warren overflow into the Otisco Valley would have been quickly checked if some eastward outlet were not provided. This is found in another rock gorge, which we call the Cedarvale channel, that leads southeast from Marcellus to the Onondaga Valley. A great part of the excavation of this gorge was done pari passu with the cutting of the gulf and by the same water, but the initial height of the outlet must have been less than the height of Lake Warren.

Theoretically the Warren waters entered this region with an elevation of more than 880 feet. Evidence of erosion at near this level appears in a cliff on the west side of the valley, 1 mile south of the intake, which has the appearance of stream cutting. This is near Mud Pond. On the east side of the channel, at the east-and-west road, one-half mile below the intake, is a gravel plain at 880 ± feet, which is probably a flood plain of the early river.

THE WITHDRAWAL FROM LAKE WARREN TO LAKE ONTARIO.

LAKE DANA (LAKE LUNDY?)

In falling from the level of Lake Warren to that of Lake Iroquois the glacial waters appear to have made brief halts at several levels below the lower beach of Lake Warren. These halting places are indicated by weak beaches. Of these temporary lake levels probably the most important is one which has recently been given the name Lake Dana by Fairchild.[1] In explanation of the halting at this level Fairchild has suggested the great resistance to erosion offered by the limestone which underlies the Cedarvale channel near Marcellus, it being thought that the Cedarvale channel was utilized by the falling waters down to that level. The shore of this lake has as yet been but partly traced, the most important section being on the west side of the valley of Seneca Lake in the vicinity of Geneva, N. Y. It has there been given the name Geneva because of this relationship to

[1] Bull. Geol. Soc. America, Vol. X, 1899, pp. 56–57.

the town site. Fairchild states that the correlation of the Geneva beach with the Cedarvale channel is still theoretical, but that the knowledge of the problem, together with the aid of the topographic sheets, is sufficient to give great confidence in the accuracy of this correlation. He remarks further that Lake Dana existed perhaps a century, or several centuries; yet, as compared with Lake Warren, it had a brief life.

There is but one place in western New York where the writer has noted evidence of a shore at the Lake Dana level. A gravel deposit at West Seneca, south of Buffalo, which seems to be the product of lake waves, stands about 180 feet below the level of the Forest beach, and is theoretically a continuation of the Geneva beach. It follows the crest of a narrow ridge which rises just above the 620-foot contour, while the lower of the two beaches on the neighboring part of the shore of Lake Warren, as shown by the Buffalo topographic sheet, stands near the 800-foot contour. This observation was made in 1893, before Fairchild had found the Geneva beach, and the ridge was traced only about a mile, as it appeared at that time to have little significance.

In this connection the "Lundy beach" of Spencer should be considered, since it stands near the level of Lake Dana. The name Lundy beach was applied by Spencer some years ago to gravelly deposits found on the borders of the Erie Basin at a level 140 to 155 feet below the Forest beach, which seemed to him to mark the shore of a lake.[1] These deposits are fragmentary, and the interpretation of shore phenomena seems open to question at several of the places cited by Spencer, if not at all of them. In view of this uncertainty, and also because the level seems to be 25 to 40 feet out of harmony with the Geneva beach, it hardly seems advisable to cite the "Lundy beach" as a feature of Lake Dana.

Faint beaches have been noted in western New York at levels still further out of harmony with Lake Dana. About 4 miles south of West Seneca, on a bluff back of Bay View, a cut bank was found at a level 60 feet higher than the gravel deposit at West Seneca, the altitude being above the 680-foot contour. This bank, which has also been observed by Taylor, apparently marks a temporary shore of the lake, yet it harmonizes in altitude with neither the Geneva nor the Lundy beach.

A few miles farther south, at North Evans, on the south bluff of Eight-

[1] Am. Jour. Sci., 3d series, Vol. XLVIII, 1894, pp. 207-212.

eenmile Creek, and thence southwestward past Derby, gravel ridges were observed by the writer and subsequently by Taylor at an altitude of fully 700 feet which have both the form and the structure of a beach. These are stronger as well as more characteristic than any of the supposed shore features at the lower levels. (See note on p. 775.)

Still other places were noted where beaches occur between the Forest beach and the shore of Lake Erie. One of the best defined is at the mouth of Chautauqua Creek, north of Westfield, N. Y. Taylor and the writer found its altitude by Locke level to be 34 feet above the surface of Lake Erie (in August, 1899), or about 606 feet above tide. This is 136 feet below the highest Warren shore at Westfield, and about 100 feet below the lowest. There are several places between Westfield and the mouth of Eighteenmile Creek where a weak beach occurs at altitudes ranging from 35 to 60 feet above Lake Erie. These were examined by Taylor and the writer in 1899, and were at first thought to mark a single shore which rises more gradually toward the northeast than the shore of Lake Warren. But upon further reflection and a correction of barometric determinations, by means of the topographic maps of that region, it seems quite as probable that they are merely incidental shore phenomena of a falling lake.

In view of the fragmentary character and the lack of harmony in level presented by these weak shore lines on the borders of the Erie Basin, it will probably be a difficult matter to establish satisfactorily the extent of Lake Dana or the equivalents of the Geneva beach.

The lowering of the lake level from Lake Dana to Lake Iroquois seems to have been accomplished by the withdrawal of the ice sheet and the uncovering of successively lower channels leading toward the Mohawk Valley. Fairchild states that the district from 15 miles southwest of Syracuse to 12 miles east was apparently the critical region, because a broad expanse of the low Ontario plain (400±; see Pl. I) meets abruptly the elevated plateau, and here the ice body lingered in its last effort to dam the Huron-Erie-Ontario waters from the Mokawk-Hudson Valley. But as yet the full succession of events and the relationship of channels subsequent to Lake Dana have not been determined. The history is partially obscured in the low Syracuse district by the changes in hydrography which have occurred since the ice removal. These, as stated by Fairchild, are (1) the possible existence of a pre-Iroquois water body with elevation toward

500 feet and consequent deltas and silting; (2) the primitive Iroquois with elevation much under 440 feet; (3) the rise of Iroquois to 440 feet and consequent filling of former channels, and (4) the stream erosion subsequent to Iroquois.

LAKE IROQUOIS.

This lake, which occupied the Ontario Basin and discharged eastward past Rome, N. Y., into the Mohawk Valley, will here receive only a brief notice, for the writer has given but little attention to its shores and outlet. Furthermore, it lies mainly outside the district under discussion. The portion of its shore from near Toronto, Ontario, around the western end of the lake and along its southern shore attracted notice in the early days of settlement. It was utilized as a trail by the red men and adopted for a highway by the early white settlers. The name Iroquois, applied by Spencer, was given it because of its use as a trail by an Indian tribe of that name. The beach as determined by Spencer has an altitude of but 362 feet at the west end of Lake Iroquois, near Hamilton, Ontario. Spencer has found a marked rise on the north shore, the altitude at Trenton, Ontario, about 140 miles by direct line from Hamilton, being 632 feet. The south shore shows a gradual rise from Hamilton eastward to the vicinity of Rochester, its altitude there as shown by the topographic sheet being about 435 feet, but it lies so nearly at right angles with the axis of uplift from Rochester eastward to the Rome outlet as to be nearly horizontal. From the Rome outlet northward the rise is very marked, the altitude being 440 feet in the vicinity of the Rome outlet and 675 feet at Adams Center, only 60 miles to the north. The rise is thought by Gilbert to be even greater, for uplift was in progress while the beach was forming, so that it presents a compound form north of the outlet. The upper members of the compound beach join the lower members upon approaching the outlet, but are thought to pass below them in the part of the lake which extended south farther than the outlet.

Lake Iroquois was apparently held up to the level of the Rome outlet by the body of ice which still occupied the St. Lawrence Valley. Upon the withdrawal of that ice the sea entered the St. Lawrence Valley and the Lake Ontario Basin, there being a beach containing marine shells exposed at the eastern end of the lake. This beach stands very nearly 200 feet below the Rome outlet. It passes below lake level near Oswego, N. Y., as determined by Gilbert. The discovery of a marine shore line at this level

has recently been supplemented by Coleman's discovery of fresh-water shells in the Iroquois beach near Toronto. It now seems well established that Lake Iroquois stood nearly 200 feet above sea level.

This determination is of value in working out the altitudes of the glacial lakes which preceded Lake Iroquois. It follows that Lake Warren, which stood about 450 feet above Lake Iroquois had an altitude not far from 650 feet above the sea, while Lake Whittlesey stood slightly over 700 feet, and Lake Maumee at its highest stage stood about 750 feet. These altitudes are but 30 to 40 feet lower than the present altitudes in the western part of the Lake Erie Basin, and covering, as they do, several lake stages, they bear testimony to long-continued stability in that region.

Note.—In eastern Michigan A. C. Lane has found a well-defined beach about 50 feet below the lowest of the Lake Warren beaches, or 690 to 700 feet above tide, which he has named the Grassmere beach. About 20 to 30 feet below the Grassmere is a fainter shore line which he has named the Elkton beach.[1] W. H. Sherzer has recognized the Grassmere beach in southeastern Michigan, and has traced it a short distance into Ohio. It there stands between 610 and 620 feet above tide, or about 40 feet above Lake Erie. He finds the lowest Lake Warren shore to be below the 660-foot contour.[2] The Grassmere beach may be a continuation of the beach at Derby, N. Y., noted on page 773, but as yet the plain south of Lake Erie has not been examined with sufficient thoroughness to warrant an opinion. In eastern Michigan and in the adjacent part of Canada a strong beach known as the Algonquin appears at the south end of Lake Huron at a level only a few feet above the present lake surface, but northward it rises to a much greater altitude.[3] The Algonquin beach of the Huron basin, it is thought, may be of similar age to the Iroquois beach of the Ontario basin, but further study is necessary to insure satisfactory correlations.

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[1] Geol. Survey Michigan, Vol. VII, 1900, part 2, pp. 73–75, Pl. VIII.

[2] Ibid., pp. 141–143, Pl. VII.

[3] J. W. Spencer: Am. Jour. Sci., 3d series, Vol. XLI, 1891, pp. 12–21.

CHAPTER XVII.

SOILS.

SOURCES OF SOIL MATERIAL.

The soils of the glaciated portion of the Ohio River Basin and of the Lake Erie Basin are very largely derived from the glacial drift and the loess and lacustrine silts that cover the drift. The underlying rocks are indirectly a source of much material, since their decomposed surface portions were incorporated in the drift, but they constitute a minor source so far as direct contribution is concerned.

The great agencies involved in producing the soils of the glaciated district—the ice sheet, the glacial lakes, and the glacial streams—have long since ceased to operate, but modern streams are still at work spreading alluvium over valley bottoms in their flood stages. The small lakes that remain in the depressions of the drift are precipitating marl deposits and carrying on their borders a vegetal growth which will some day yield a rich soil as the lakes are lowered. Vegetation has also been enriching the soil with humus over much of the plane-surfaced drift from the time it first gained a foothold on the drift surface; while organisms of various kinds, both plant and animal, have united with the atmospheric agents to break up the soil and mix it thoroughly.

The preceding discussion has shown that there are wide differences in the ages of the drift deposits, there being deposits of Kansan or pre-Kansan, of Illinoian, of Iowan, of early Wisconsin, and of late Wisconsin age. The exposed portion of the oldest (Kansan or pre-Kansan) drift in northwestern Pennsylvania constitutes but a limited part of the drift surface, amounting to but a few hundred square miles. The Illinoian drift of northwestern Ohio and southeastern Indiana extends over several thousand square miles outside the limits of the Wisconsin drift, but it is covered so deeply by silt of later (Iowan) age that it forms the soil only on the valley slopes or in

places where the underlying silt has been eroded. The surface soil of that region is mainly on the Iowan silt, while the Sangamon soil that was formed between the Illinoian and Iowan stages of glaciation has been buried beneath that silt. The early Wisconsin drift within this region has a somewhat limited exposure. The remaining part of the drift surface, comprising a large area, is therefore of late Wisconsin age.

The unglaciated portion of the Ohio River Basin is covered somewhat widely by Pleistocene deposits. There are not only the valley deposits brought down to the Ohio from the glaciated districts by glacial and modern streams, but also deposits on the uplands of a fine silt apparently of Iowan age. The soil of the flat portions of uplands in southeastern Ohio and even in States south of the Ohio is formed from this silt. Much of the unglaciated part of the Ohio River Basin is, however, so broken that the silt has been removed and soil is being formed from the Paleozoic rock formations, as it was before the deposition of the silt or the advent of Pleistocene glaciation. There are uneroded places in which the residuary clays formed by the disintegration of the rock surface may be clearly distinguished in color and texture from the overlying silt of Pleistocene age

CLASSES OF SOIL.

There are several modes of classification of soils in use, based generally on either chemical constitution or physical texture or characteristics. The classification which seems best to serve our purpose is based mainly on physical characteristics. The control which the physical characteristics exert upon moisture and temperature has been found by experimentation to be far more important than the mere chemical composition of the soil. It is found that under favorable conditions of moisture and temperature the majority of plants can readily gather sufficient food material from almost any soil.

In the Erie and Ohio basins the following classes of soils are present: (1) Residuary soils, or soils formed from the underlying rock; (2) stony clay soils, derived from the till or bowlder clay; (3) gravelly or stony soils; (4) sandy soils; (5) silts or clays of fine texture, but more or less pervious to water; (6) peaty soils with a large amount of organic material. A tabular statement is here presented which shows the origin or mode of deposition and the areal distribution of the several classes of soils.

Table of soils in the Ohio and Erie basins.

Class.	Derivation.	Areal distribution.
Residuary	Decay of the underlying rocks.	Unglaciated portion of the Ohio basin, where silt as well as glacial material is absent, and also on valley slopes within the glaciated region where the drift covering is too thin to afford a soil.
Stony clay	Glacial	On a large part of the moraines, and much of the till plains of Wisconsin age; along valley slopes in the Illinoian drift; very limited exposure on the older drift of northwestern Pennsylvania.
Gravelly, or stony.	Glacial, glacial outwash, streams, wave-action.	On the older drift of northwestern Pennsylvania; in interlobate moraines of Wisconsin age; to a limited extent as kames on till plains and moraines of Wisconsin age; to a very limited extent in the Illinoian drift; as glacial outwash along valleys in connection both with the Wisconsin drift and the older drift, and as outwash aprons to a limited extent on the outer border of moraines; as stream deposits both along glacial and modern drainage lines; as deltas along parts of the shores of the glacial lakes where vigorous streams entered; as wave products along parts of the old lake shores.
Sandy	Glacial drainage, streams, lakes, wind.	The valley deposits vary in coarseness with the strength of the current, and contain much sand both in the glacial and modern deposits; beaches of glacial lakes are composed largely of sand, and the lake bottoms are covered to a limited extent with sand; the beaches of Lake Warren are especially sandy; wind has drifted the sand into dunes to a limited amount in northwestern Ohio, and in a few places farther east, in the area covered by glacial lakes.
Silty or clayey	In part by slowly flowing waters, probably in part by wind; also as a sediment in glacial lakes.	Mainly outside the limits of the Wisconsin drift throughout the exposed portion of the Illinoian drift, and on flat portions of the unglaciated districts bordering the Ohio, both in valleys and on bordering uplands; the lower part of the Scioto and Grand River basins, much of the Maumee basin, and flat areas in northern Ohio, also carry a surface clay with few pebbles, partly a sluggish stream deposit and partly a lake sediment; silt deposits are of limited extent in northwestern Pennsylvania and western New York, chiefly in lowlands and valleys.
Peaty or organic	Vegetal accumulations and shell deposits.	Locally in the Erie basin and the glaciated portion of the Ohio River basin, where drainage is imperfect; the most conspicuous deposits are in basins and lakes inclosed among the morainic knolls, but there are extensive peat bogs in northern Ohio between moraines where adequate drainage has not been developed.

RESIDUARY SOILS.

The residuary soils show variations which correspond in a rude way with variations in the structure of the rocks from which they are derived. In regions underlain by limestone there is usually a reddish-brown clay. In shale areas the residuary material is an adhesive clay varying in color to correspond with the underlying shale In sandstone and freestone areas the residuary material is siliceous rather than clayey or argillaceous. It often presents a color and texture similar to the deposits of Iowan silt that overlie it so that the line of junction is difficult to determine. With proper rotation of crops the residuary soils are usually productive and profitable for agriculture, though they can scarcely compete with the soils formed on glacial drift. The fertility of the unglaciated tracts is also difficult to maintain because of the steepness of the slopes and the resulting great erosion.

STONY-CLAY SOILS.

The soils formed on the bowlder clay or till are usually very productive, being composed of a varied rock material, a large part of which is in a sufficiently fine state of division to be available for plant food. In physical constitution also it is well calculated for agriculture, being sufficiently porous, as a rule, to allow air and water to penetrate it readily. Portions of it, however, have so compact a texture that underdraining by tile has been found necessary. In general all grains and fruits suitable to the latitude will flourish, especially where the surface is rolling or well drained. It has been found necessary to use fertilizers to insure a wheat crop on land that has been in cultivation for periods of forty to fifty years, and advantageous on ground which has been under cultivation but a few years, a fact which testifies to the value of certain chemical ingredients to the growth of that cereal. The importance of the stony-clay soil may be appreciated from the fact that it constitutes the soil of the major part of the great agricultural States of Ohio and Indiana, as well as the most productive portions of western New York and northwestern Pennsylvania.

GRAVELLY OR STONY SOILS.

On the older drift of northwestern Pennsylvania and the gravelly portions of the moraines of Wisconsin age throughout the region under discussion as well as on the kames, the soil is usually stony. There are, however, but a few places where there is not a sufficient matrix of fine

material to afford sustenance to plants. Indeed, the grains and fruits are found to flourish in this class of soil. The gravelly outwash aprons bordering the moraines and the deposits along the lines of discharge for glacial waters usually carry a capping of loam from a few inches to several feet in depth, which adds to their productiveness. It is only the trees and the deep-rooting plants that extend down to the gravel. The deltas and gravelly portions of beaches on the shores of the glacial lakes usually carry sufficient sand and loam as a matrix to supply the needs of plants.

SANDY SOILS.

The sandy soils are as a class the least productive of the whole series. They are, however, confined to narrow strips along valleys and to small areas on the borders of the glacial lakes. The most extensive tracts are near the shores of the glacial lakes Maumee and Warren in northwestern Ohio and the neighboring part of Michigan, and there they cover but a few townships. Elsewhere they are in narrow strips, usually but a fraction of a mile and often but a few yards in width, that follow the old shore lines.

SILTY SOILS.

The silty soils display considerable variation in texture, some being a compact clay nearly impervious to water, others a loamy clay in which water has a moderate movement, and still others a loam in which water has a free movement. The silt that covers the Illinoian drift in southeastern Indiana and southwestern Ohio is nearly impervious to water, and its flat areas are subject to flooding in wet seasons and to baking in seasons of drought. The term "slash land" has been applied to these poorly drained areas. The soil is in places underlain at the depth of a few inches by an ochery clay or ferruginous crust which is exceedingly refractory and difficult to break up. This ferruginous crust is so extensive here and also in districts farther west that it merits careful investigation as to methods for breaking it up and rendering more productive a soil which seems otherwise well calculated for profitable agriculture. The silt that covers the Wisconsin drift in parts of the Scioto, Grand River, and Maumee basins is usually sufficiently porous to permit water to pass up or down through it. Although the areas of Wisconsin drift which are covered with silt are generally so flat that some flooding occurs in wet seasons, the passage of water through the silt is sufficiently free to prevent baking in seasons of

drought. The silt with loosest texture is usually found on the borders of the valleys. In places its coarseness is such that it might perhaps be better termed a sand, though the term loam is more commonly applied to it by the residents. Its texture is so open as to render it very productive.

The silt which covers the residuary clays in unglaciated parts of the Ohio Basin is on the whole sufficiently loose textured and sufficiently varied in chemical constituents to afford a fertile soil. It remains only in small patches on the uplands, but is extensively preserved in the lowlands and abandoned valleys of southeastern Ohio and neighboring parts of West Virginia and Kentucky.

PEATY OR ORGANIC SOILS.

The peaty and organic soils occur in basins or in poorly drained tracts where the rank vegetation becomes submerged at certain seasons and is thus prevented from atmospheric decay. When drained, the peat being allowed to ripen and become warm, these bogs will in many instances yield large crops of potatoes, onions, celery, and other garden truck. These bogs, which for years stood as waste land, are thus becoming a productive class of soil.

NOTE.—It has been thought best to attempt no special discussion in this monograph of the wells and other water supplies of the region covered, for the Survey has already published several special papers on these subjects. The water supplies of Indiana and Ohio have received a general discussion by the present writer in Part IV of the Eighteenth Annual Report of the United States Geological Survey, and the wells of Indiana have been treated in some detail in Water-Supply and Irrigation Papers Nos. 21 and 26. Orton has discussed the rock waters and the flowing wells of Ohio in Part IV of the Nineteenth Annual Report, and Rafter has included western New York in his discussion of the water resources of New York in Water-Supply and Irrigation Papers Nos. 24 and 25. In addition to the material in the papers just mentioned many well sections and other data concerning water supplies may be found in the present report, chiefly in connection with the discussion of the structure of the drift.

INDEX.